Executive Summary

Since May 1985, the Central Valley Regional Water Quality Control Board has conducted a water quality monitoring program in the San Joaquin Valley of California to assess the impact of agricultural subsurface drainage on wetland water supply channels in the Grasslands Watershed and on the San Joaquin River. The Grasslands Watershed is a 370,000-acre area, west of the San Joaquin River covering portions of Merced and Fresno counties between the Tulare Lake Basin and the Orestimba Creek alluvial fan. The watershed contains both farmed land, including a 90,000 acre area known as the Drainage Problem Area (DPA), and approximately 100,000 acres of wetland habitat, including State and Federal wildlife refuges and private gun clubs. During the period covered by this report, subsurface drainage from the DPA was routed through the wetlands to the San Joaquin River. The watershed also contains the remains of Kesterson Reservoir, a former holding pond for agricultural subsurface drainage which was converted to upland habitat when elevated levels of selenium in the drainage were found to be hazardous to waterfowl.

Over the course of the monitoring program, water quality samples have been collected from eight locations along the lower San Joaquin River, between the Mendota Pool and the Sacramento-San Joaquin Delta, and 37 sites within the Grassland Watershed. Analyses performed have included temperature, electrical conductivity, pH, minerals, and trace elements. All water quality information collected has been published in a series of annual water year reports (a water year extends from October 1st of one year to September 30th of the next), and are available from the Central Valley Regional Water Quality Control Board. This report consolidates and summarizes the electrical conductivity, boron and selenium data collected between May 1985 and September 1995. The narrowed focus reflects the potential of these constituents to adversely effect waterfowl and agriculture.

The general study area has had a highly managed hydrology since implementation of the Central Valley Project (CVP). Most of the San Joaquin River flow is diverted into the Friant-Kern Canal, leaving the river channel upstream of the Mendota Pool dry except during periods of wet weather flow and major snow melt. During the irrigation season, the flows in the river between the Mendota Pool and Salt Slough consist largely of irrigation water supplies that are diverted from the river at Sack Dam, irrigation tailwater discharged from the Bear Creek Channel and groundwater accretions. Salt Slough and Mud Slough are the principal drainage arteries for the Grassland Watershed and add significantly to the flows and waste loads in the San Joaquin River upstream of its confluence with the Merced River. Discharges from three major river systems, the Merced, Tuolumne, and Stanislaus Rivers, dominate flow and quality of discharges from the east side of the Lower San Joaquin River Basin, while flows from the west side of the river basin are dominated by agricultural return flows since westside streams receive no snowmelt to maintain their flows and most would go dry during the summer months.

Historically, much of the Grassland Watershed was subject to annual flooding that provided the primary source of natural flows in the water bodies within the area. The CVP controlled the flooding and imported water from the Delta was used to replace the San Joaquin River water diverted into the Friant-Kern Canal. In order to deliver the imported water to agricultural lands and artificially maintained wetlands, an extensive water distribution system was developed. Consisting of new channels, modification (channelization) of existing natural channels, and interconnection via hydraulic structures, this new system drains to the San Joaquin River via Salt Slough and Mud Slough. Agricultural irrigation return flows and wetland drainage are the dominant sources of water leaving the watershed through these two sloughs.

The San Joaquin River Index is used to classify water year type in the river basin based on total runoff (SWRCB, 1995). The period of record addressed in this report contained a wide variety of runoff year types, including two of the three highest runoff years since record keeping began in 1906, and six consecutive years of drought.

During low flow periods, discharges from Mud Slough (north) and Salt Slough can have a major effect on both San Joaquin River quality and quantity. The combined total flows in the sloughs contributed an average of 64% of the total flow in the river upstream of its confluence with the Merced River between WYs 86 and 95 with a maximum of 82% during WY 89. The combined flows from the sloughs contributed an average of 13% of the total river flow entering the Sacramento-San Joaquin Delta between WYs 86 and 95, with a maximum of 21% during WY 90.

Discharges from Mud Slough (north) and Salt Slough contain a combination of agricultural return flows, wetland releases, and groundwater seepage. These discharges typically contain elevated concentrations of EC, boron and selenium. Salt Slough median EC and boron trends both show steady, gradual increases over the 10-year study with a slight drop in WY 95. Annual median EC and boron concentrations in Mud Slough (north) were consistently higher than in Salt Slough until the trend was reversed in WY 93. The peak annual median boron concentration and EC that occurred in Mud Slough (north) during WY 91, correspond to the lowest total flow in the 10-year study.

The annual fluctuations seen in overall median selenium concentrations can be partly attributed to the hydrology of the area. Since the primary source of selenium is subsurface agricultural drainage from the 90,000-acre Drainage Problem Area, the presence of selenium reflects the presence of subsurface drainage. Between WYs 86 and 88, subsurface drainage was discharged alternately between the two sloughs. Beginning in WY 89, water agency managers began to actively divert subsurface drainage to Salt Slough through the Porter-Bake Bypass. Without the subsurface drainage, selenium concentrations in Mud Slough remained low, typically below 2 μg /L while concentration in Salt Slough stayed closer to 15 μg/L.

Seasonally, peak EC, boron and selenium concentrations occurred during January and February in Salt Slough. Conversely, in Mud Slough (north) peak EC and boron concentrations tended to occur in May, June and July with selenium peaking during July and August. These trends suggest different constituent sources in conjunction with varying dilution flows. The early seasonal elevated levels in Salt Slough may be associated with pre-irrigation practices that produce increased subsurface drainage. Later peaks of EC and boron in Mud Slough may be associated with tail water and late wetland drainage.

Annual median constituent concentrations have fluctuated at both the San Joaquin River at Hills Ferry Road and the San Joaquin River at Crows Landing Bridge sites since WY 86. (The Hills Ferry Road site is downstream of the confluence with Mud Slough (north) and Salt Slough but upstream of the Merced River inflow, while the Crows Landing site is downstream of the Merced River.) This fluctuation is due to upstream dilution flows. During higher than normal precipitation years, east side tributary and storm flows dominate characteristics at the sites. During normal to below-normal water years, Mud Slough (north) and Salt Slough dominate the characteristics. Annual median concentrations were elevated during critically dry water years at both sites and declined during wet water years. The dilution effect of the Merced River was evident in the consistently lower concentrations found at the Crows Landing site when compared to the Hills Ferry site. Farther downstream, constituent concentrations continued to decrease with respect to site location downstream of an east side tributary inflow and the subsequent dilution that takes place.

Seasonally, data indicates that EC and boron concentrations increase in the Lower San Joaquin River in December and remain elevated until mid-summer. Selenium concentrations correspond to agricultural irrigation events and the discharge of subsurface drainage from the Grassland Watershed. Peak subsurface drainage discharges occur during pre-irrigation (February and March) and remain relatively constant during the irrigation season (May through August).

The Central Valley Regional Board adopted selenium and boron water quality objectives (WQOs) for the lower San Joaquin River in 1988 (Resolution #88-195). The WQOs depend on site location, water year type and season. In December 1992, the U.S. Environmental Protection Agency promulgated a 5μg/L 4-day average and 20μg /L maximum selenium criteria for the San Joaquin River. The promulgated objectives applies directly to permitted point source discharges and serve as a goal for the development of nonpoint source control efforts.

As specified in the San Joaquin River Basin Plan (December 1988), compliance monitoring for selenium and boron WQOs occurs on the San Joaquin River at the Crows Landing Bridge site downstream of the Merced River inflow, and at the Hills Ferry site upstream of the Merced River inflow. Exceedances of both objectives appear to correspond to typical periods of pre-irrigation and wetland releases (February through April) and the mid-growing season (June and July). A higher rate of exceedances occurs during critical-dry water years as compared to wet water years.

In May 1991, the State Water Resources Control Board adopted electrical conductivity (salinity) objectives for the San Joaquin River near Vernalis, the river's confluence with the Sacramento-San Joaquin Delta. Based on water quality information collected since WY 86, had the adopted salinity objectives been in place over the entire study period, they would have been exceeded almost continuously between April and August and frequently between December and February, during each critically-dry water year. The salinity objectives would usually have been met during wet water years.

Compared with discharge, loads of salt, boron and selenium from the DPA accounted for a disproportionately high percentage of total downstream loads. Salt from the DPA accounted for an average of 51 percent of the annual load discharged from the Grassland Watershed and 29 and 24 percent of the annual load in the San Joaquin River immediately downstream of the Merced River and as it enters the Sacramento-San Joaquin Delta, respectively. The highest annual salt loads for the San Joaquin River sites occurred during wet water years while the lowest loads corresponded with the years of the lowest discharge from the DPA, critical water years 1991 and 1992.

The pattern of boron loading is similar to salt except that a higher percentage of boron in the watershed comes from the DPA. Boron from the DPA accounted for an average of 67 percent of the load discharged from the Grassland Watershed, 51 percent of the San Joaquin River load downstream of the Merced River, and 45 percent of the load in the river as it enters the Delta.

Although salt and boron loads generally increase as you move downstream, selenium loads do not follow the same pattern. Selenium loads discharged from the DPA are higher than the loads discharged from the Grassland Watershed for all years except 1990. Loads for the DPA are also higher than loads for the San Joaquin River downstream of the Merced River except for the wet water years of 1986 and 1995.

The combined effects of reduced water supplies and improved on-farm irrigation practices are apparent in the large reductions in loads of all constituents that occurred from the DPA between water years 1989 and 1992. Although these load reductions were credited with less severe and less frequent exceedance of water quality objectives in the San Joaquin River at Crows Landing, increased concentrations were noted in the water bodies within the Grassland Watershed. These increased concentrations were likely due to the reduced availability of better quality tail water that would have reduced the concentrations in the drainage water. The reduction in tail water results from improved irrigation management and less water delivered. The trend toward reduced loads was reversed in water year 1993 and loads increased dramatically in water year 1995. In water year 95 boron and selenium loads were the highest on record since monitoring began in 1985. The leaching of accumulated salts built up in the soil profile during six years of drought may account for some of the load increases.

The period of record presented in this report, water years 1986 through 1995, corresponds to the time period when initial efforts to improve water quality focused on irrigation management. Although improvements were apparent in the Lower San Joaquin River, water quality objectives continued to be exceeded in both the river and water bodies within the Grassland Watershed. Information from this report and a separate report which calculates mass discharge of constituents from the Grassland Watershed for the same time period (Grober et al., 1998), will be used to compare the initial efforts to efforts in subsequent water years. Those future efforts include consolidating agricultural subsurface drainage and improving water quality through load reductions.

INTRODUCTION

The Agricultural Unit of the Central Valley Regional Water Quality Control Board (Regional Board) initiated a water quality monitoring program in May 1985 to evaluate the effects of subsurface agricultural drainage on the water quality of canals, drains, and sloughs in the Grassland Watershed in western Merced County and on the Lower San Joaquin River. The Grassland Watershed is located west of the San Joaquin River between the Tulare Lake Basin and the Orestimba Creek alluvial fan. Water quality samples were also collected at eight monitoring sites along a 60-mile section of the River extending from near Lander Avenue in Merced County to Airport Way near Vernalis in San Joaquin County (Figure 1). The purpose of this monitoring program was to compile an on-going database of selected inorganic constituents found in the San Joaquin River and agricultural drains that discharge to and flow through the Grassland Wildlife Area before entering the San Joaquin River. This database is used both to assess the effects of agricultural drainage water on the quality of the San Joaquin River and to develop and evaluate agricultural drainage reduction programs in the San Joaquin River Basin. A long-term database is essential to assess the effects of the implementation of regional agricultural drainage reduction programs on overall river water quality. Information gathered under this program is also being used to develop a predictive model for determining maximum salt, selenium, and boron loads which could be discharged from the study area while still meeting downstream water quality objectives (Karkoski, 1994). This report contains laboratory results and a brief summary of the water quality analysis for electrical conductivity, boron and selenium in samples collected from Water Year 1986 to Water Year 1995 (October 1985 through September 1995). Previous reports have been issued for all water quality data collected on the Lower San Joaquin River from May 1985 through September 1995 (WYs 86-95) (James, *et al.*, 1988; Westcot, *et al.*, 1989a, 1990a, 1991a, and 1992; Karkoski and Tucker, 1993a; Chilcott, *et al.*, 1995a; and Steensen, *et al.*, 1996a). Previous reports have also been issued for all water quality data collected within the Grassland Basin and present data for the period May 1985 through September 1995 (WYs 86-95) (James, *et al.*, 1988; Chilcott, *et al.*, 1989; Westcot, *et al.*, 1990b, 1991b, and 1992b; Karkoski and Tucker, 1993b; Chilcott, *et al.*, 1995b; Vargas, *et al.*, 1995; and Steensen *et al.*, 1996b).

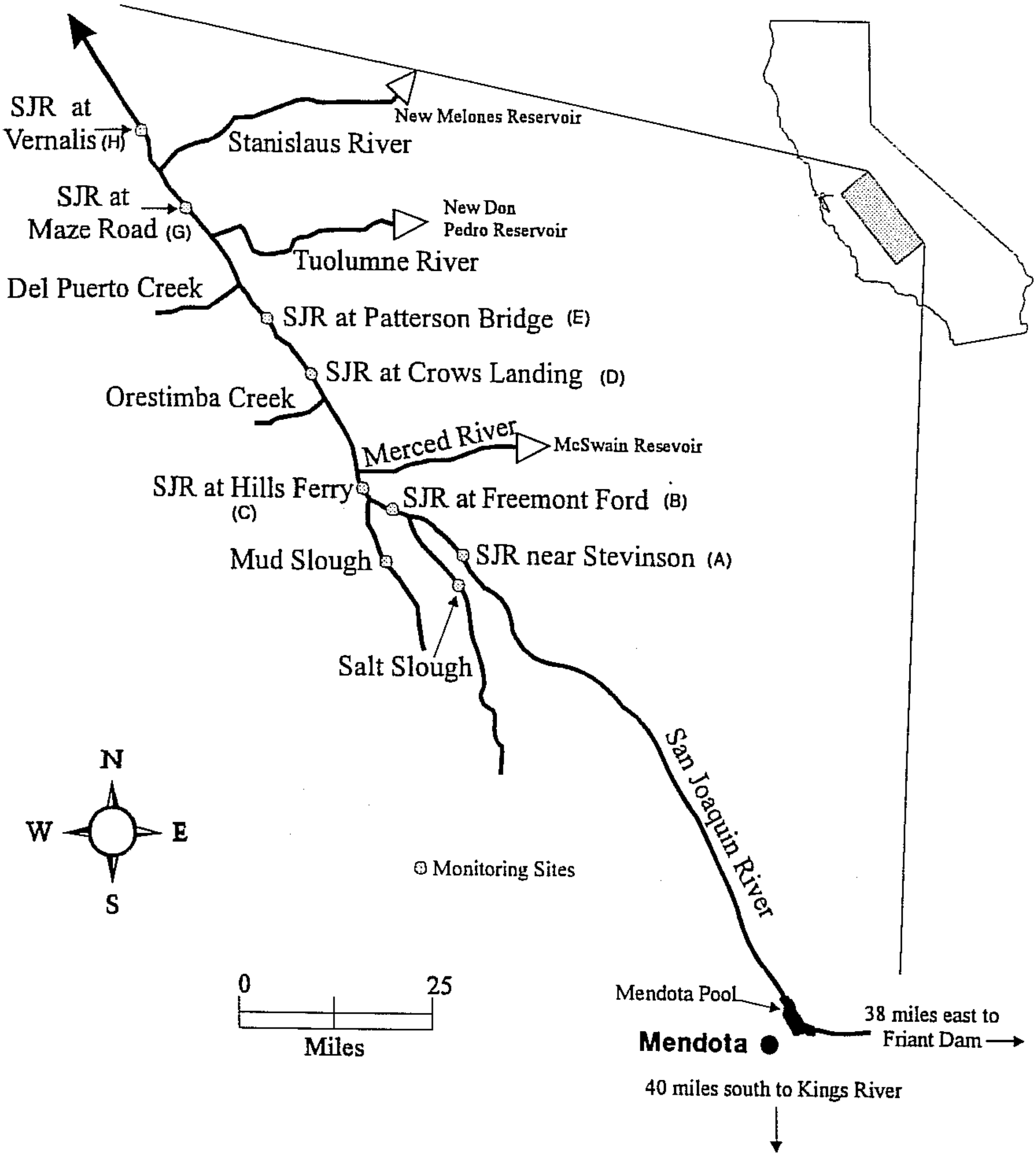
STUDY AREA

The study area consists of two units: a 60-mile section of the San Joaquin River extending from Stevinson near Lander Avenue to Airport Way near Vernalis; and the Grassland Watershed located west of the San Joaquin River between the towns of Newman and Mendota, in the San Joaquin River Basin in California.

San Joaquin River monitoring sites are located near each of the eight river over crossings on this stretch of the River (Figure 1). The San Joaquin River watershed drains approximately 13,500 square miles (Karkoski, *et al.*, 1995a). There are five major tributaries to the San Joaquin River within the study area: Salt Slough, Mud Slough (north), and the Merced, Tuolumne, and Stanislaus Rivers. Salt Slough and Mud Slough (north) drain the Grassland Watershed Area of western Merced County and discharge to the San Joaquin River in the southern portion of the study area. These two sloughs are the major source of agricultural subsurface drainage water discharges to the San Joaquin River. They carry a varying mixture of surface and subsurface agricultural drainage, operational spillage from irrigation canals, and seasonal drainage from duck ponds flooded each winter for waterfowl habitat. The agricultural and wetland dominated area of the Grassland Watershed consists of approximately 580 square miles. The Merced, Tuolumne, and Stanislaus Rivers are major east side rivers that contribute the majority of water to the San Joaquin River within the study area. In addition to the five major tributaries, there are also a number of

Lower San Joaquin River Monitoring Network

Figure-1



smaller tributaries, as well as surface and subsurface agricultural drains that discharge to the San Joaquin River within the study area. The significant inflows, monitoring sites and their locations, referenced by river mile, are listed in Table 1. A full description of the inflow points that occur in this 60-mile section of the river is in James, *et al.*, (1989).

The Grassland Watershed encompasses approximately 370,000 acres. The Grassland Watershed includes the northern and southern divisions of the Grassland Water District (GWD), and farmlands adjacent to the District. Land in this watershed is primarily used for irrigated agriculture and managed wetlands (Figure 2).

Prior to October 1996, agricultural lands east, west, and south of the GWD discharged subsurface agricultural drainage water (tile drainage) and surface runoff (irrigation tail water) through the GWD. Subsurface drainage often contains high concentrations of salts, selenium, and other trace elements. This regional drainage flowed north through the GWD, carried by a network of canals that could divert water in several possible ways before discharging into Mud Slough (north) or Salt Slough. These two sloughs are tributary to the San Joaquin River and serve as the primary drainage outlets for the Grassland Watershed.

Since May 1985, there have been 37 stations monitored at various frequencies as part of the Grassland monitoring program. These stations have been described in previous reports and they were divided into three categories: inflows to and internal flows within GWD and outflows from the entire Grassland Watershed (Table 2). Inflow monitoring stations are located on drains that discharge into the GWD and are mainly located at the southern end of the study area. Internal canals are located on drains within the GWD that carry or could carry subsurface tile drainage as it passes through, before discharging to the San Joaquin River. Outflow monitoring stations are located where drains or natural waterways flow out of the Grassland Watershed. In addition, samples were collected at the terminus of the San Luis Drain when water had collected at that point. Many of the stations described in previous reports have been altered, dropped or added over the course of the monitoring program. Most of the original inflow stations were maintained during the survey and have continuous data from May 1985 through September 1995. Several internal flow stations were maintained to assess the approximate concentration of selenium in wetland water supply canals to the GWD as well as to track movement of the drainage water. These sites include the Central California Irrigation District Main Canal (T-1) which is the main water supply to the GWD, the Porter-Blake Bypass (T-13), Santa Fe Canal at Henry Miller Road (T-5), San Luis Canal at Henry Miller Road (T-7A), San Luis Canal at Highway 152 (T-7), and the San Luis Spillway Ditch at Santa Fe Grade (T-14). Each of these sites can carry various combinations of supply and drainage water and have been monitored during the ten-year program with special emphasis during wetland flood up.

Mud Slough (north) and Salt Slough are the primary tributaries to the San Joaquin River that drain the Grassland Watershed and are described in detail in previous reports (Pierson *et al.*, 1989a and 1989b). Mud Slough (north) at the San Luis Drain (0-2A) and Salt Slough at Lander Avenue (0-4) are located near continuous flow monitoring stations operated by the U.S. Geologic Survey and are two principal stations in this monitoring program. These two sites best represent the water quality of the drainage leaving the Grassland Watershed. Los Banos Creek at Highway 140 (0-3) drains into Mud Slough (north) upstream of the San Joaquin River but downstream of the site near the San Luis Drain. Mud Slough at Newman Gun Club (0-1) represents the combined quality of Mud Slough (north) and Los Banos Creek.

Table 1. **Tributaries and Drains to the San Joaquin River Between Monitoring Stations from the Lander Avenue Bridge to Airport Way (James et al., 1989)**

River Mile	Description	Water Make-up	Sampling Period of Record
132.9	**Lander Avenue (Site A)**	R	85-95
129.7	Salt Slough	T,S	85-95
125.1	**Freemont Ford (Site B)**	R	85-95
121.2	Mud Slough	T,S	85-95
119.6	Newman Wasteway	O,S	
119.5	Newman Drainage District Collector Line A	T	
119.1	Hills Ferry Road Drain	S	
118.8	**Hills Ferry Road (Site C)**	R	85-95
118.2	Merced River	N	
117.5	Newman Drainage District Lateral Line 1	T	
117.2	Azevedo Road Drain	S	
113.4	Frietas Road Drain and South of Frietas Road Drain	S	
112	Turlock Irrigation District Lateral 6	S,O	
109	Orestimba Creek	N,S	94
107.2	**Crows Landing Road (Site D)**	R	85-95
105	Spanish Grant, Marshall Road, Moran Road Drain	S,T	
103.5	Turlock Irrigation District Lateral 5	S	
100	Ramona Lake Main Drain	S,T	
98.6	Patterson Water District Main Drain	S,T	
98.4	**Las Palmas Launching Facility (Site E)**	R	85-95
97.6	Olive Avenue Drain	S	
97.3	Lemon Avenue Drain	S	
97	Eucalyptus Avenue Drain	S	
95.2	Turlock Irrigation District Lateral 3	S	
92.9	Del Puerto Creek	N,S	
91.4	Houk Ranch Drain	S,T	
90.3	Turlock Irrigation Lateral 4	S	
89.1	**Grayson Road (Site F)***	R	85-92
87	Old San Joaquin River Channel	S	
83.7	Tuolumne River	N	
81.1	Merced Irrigation District Lateral 4	S	
79.9	Hospital/Ingram Creeks	S,T	
78.9	Center Road Drain	S	
77.6	Blewett Drain	S,T	
77.4	Blewett Drain	S	
77.3	**Maze Boulevard (Site G)**	R	85-95
74.9	Stanislaus River	N	
73.6	**Airport Way (Site H)**	R	85-95

LEGEND

R San Joaquin River Water
S Surface Agriculture Drain
T Subsurface Agriculture Drain
N Natural Stream
O Operation Spillage
* Deleted from monitoring program after WY93

Figure 2. The Grassland Watershed Within the San Joaquin River Basin

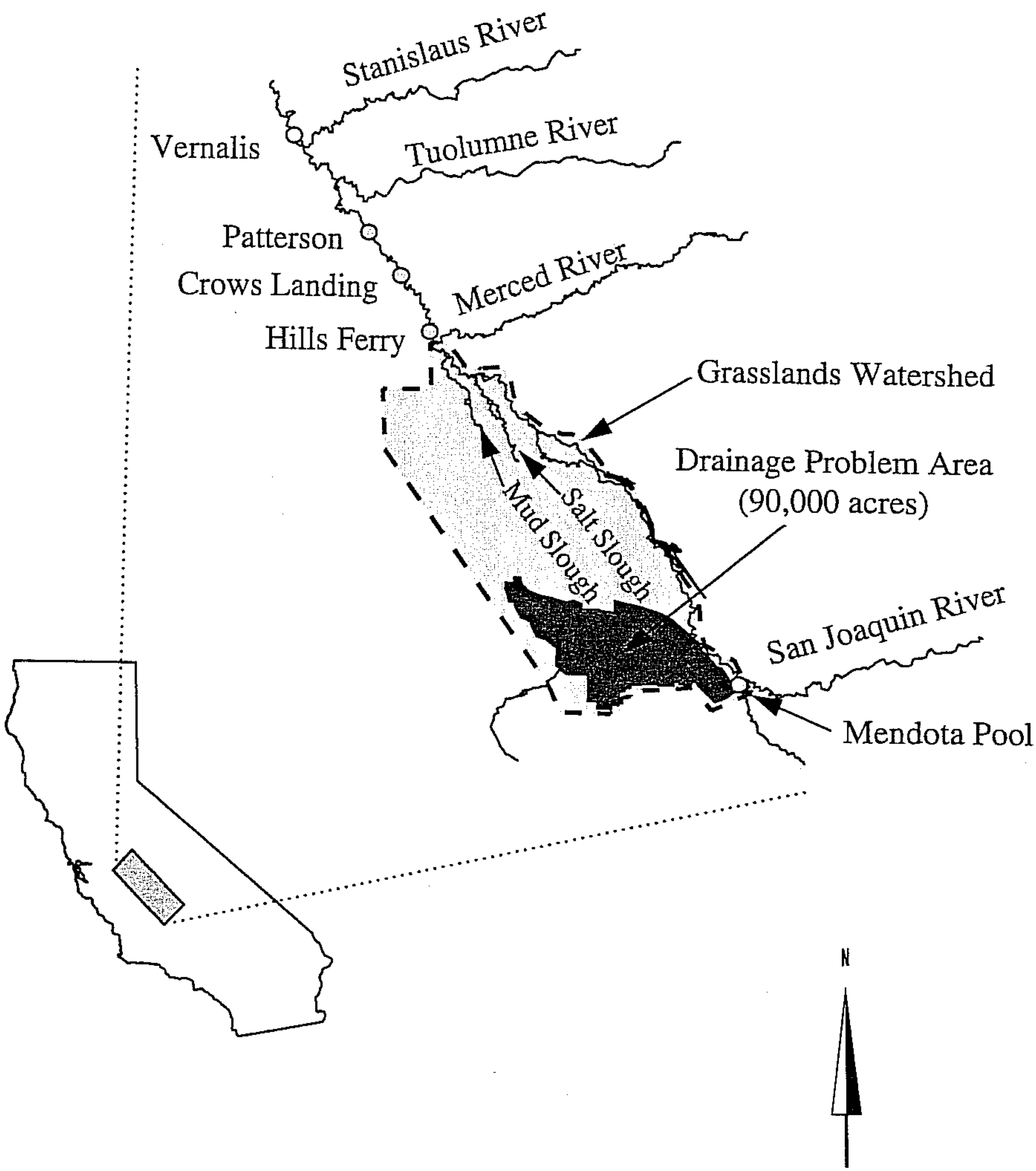


Table 2. Water Quality Monitoring Sites in the Grassland Watershed: WYs 85 - 95.

Map Index†	RWQCB Site ID	Site Name	Site Type*	Period of Record
I-1	MER556	Main (Firebaugh) Drain @ Russell Avenue	Inflow	85-95
I-2	MER501	Panoche Drain @ O'Banion Gauge Station	Inflow	85-95
I-3	MER552	Agatha Inlet (Mercy Springs) Drain	Inflow	86-93
I-4	MER506	Agatha Canal @ Mallard Road	Inflow	85-95
I-5	MER507	Helm Canal	Inflow	85-86
I-6	MER504	Hamburg Drain near Camp 13 Slough	Inflow	85-95
I-7	MER505	Camp 13 Slough at Gauge Station	Inflow	85-95
I-8	MER502	Charleston Drain @ CCID Main Canal	Inflow	85-95
I-9	MER555	Almond Drive Drain	Inflow	86-95
I-10	MER509	Rice Drain @ Mallard Road	Inflow	85-95
I-11	MER521	Boundary Drain @ DFG Pump	Inflow	85-95
I-12	MER528	Salt Slough Ditch @ Hereford Road	Inflow	85-95
I-13	MER513	Garzas Creek @ Hunt Road	Inflow	85-87
T-1	MER510	CCID Main @ Russell Avenue	Internal Flow	85-95
T-2	MER511	CCID Main @ Almond Drive	Internal Flow	85-87
T-3	MER512	CCID Main @ Gun Club Road	Internal Flow	85-87
T-4	MER540	Santa Fe Canal @ Highway 152	Internal Flow	85-87
T-5	MER519	Santa Fe Canal @ Henry Miller Road	Internal Flow	85-87;92-95
T-6	MER517	Santa Fe Canal @ Gun Club Road	Internal Flow	85-87
T-7	MER532	San Luis Canal @ Henry Miller Road	Internal Flow	92-95
T-7A	MER527	San Luis Canal @ Highway 152	Internal Flow	85-95
T-8	MER514	Los Banos Creek @ Gun Club Road	Internal Flow	85-87
T-9	MER518	Eagle Ditch @ Gun Club Road	Internal Flow	85-87
T-10	MER516	Mud Slough @ Gun Club Road	Internal Flow	85-87
T-11	MER515	Fremont Canal @ Gun Club Road	Internal Flow	85-87
T-12	MER553	Gustine Sewage Treatment Plant	Internal Flow	85-87
T-13	MER548	Porter-Blake Bypass	Internal Flow	92-95
T-14	MER537	San Luis Spillway Ditch @ Santa Fe Grade	Internal Flow	92-95
O-1	MER551	Mud Slough @ Newman Gun Club	Outflow	85-95
O-2	MER541	Mud Slough (north) @ Highway 140	Outflow	85-90
O-2A	MER542	Mud Slough (north) downstream of San Luis Drain	Outflow	90-95
O-3	MER554	Los Banos Creek @ Highway 140	Outflow	85-95
O-4	MER531	Salt Slough @ Lander Avenue	Outflow	85-95
O-5	MER530	Salt Slough @ Wolfsen Road	Outflow	85-88
O-6	MER543	City Ditch	Outflow	85-88;90-92
O-7	MER534	San Luis Drain @ Highway 152	Outflow	93-95
O-8	MER536	Mud Slough (north) upstream of San Luis Drain	Outflow	93-95

† Refers to Appendix Figure 1A.
* Relative to Grassland Water District
WY = Water Year (1 October through 30 September)

METHODS

Sampling

The frequency of sample collection for this monitoring program consisted of weekly, monthly, and quarterly grab samples depending on site location and the year monitored. As an example, a summary of the water year 1995 (WY 95) monitoring program is outlined in Table 3. Water temperature, pH, electrical conductivity (EC), and sample time were recorded in the field for each site. There were fourteen sites sampled weekly and an additional sixteen sites sampled either monthly or quarterly. Laboratory analyses for total recoverable selenium, boron and EC[1] were performed on all samples. Selected sites were also monitored for copper, chromium, nickel, lead, zinc and molybdenum on a monthly or quarterly basis. Sampling frequency was reduced to quarterly at stations which had shown consistent constituent concentrations between WY 86 and WY 94.

Water samples were collected in polyethylene bottles. The selenium and trace element sample bottles were rinsed with dilute nitric acid and deionized water in the laboratory before use. All sample bottles were rinsed three times with the water to be sampled prior to sample collection. Selenium, boron, and trace element samples were preserved by lowering the pH to less than 2.0 within 24 hours of collection, using reagent grade nitric acid. Potential contamination from the acid was evaluated by submitting a ten-fold increase in the amount of acid used to control pH in a deionized water matrix and analyzing for the trace elements of concern. All reported recoveries for check samples were below the analytical detection limit. All samples were kept on ice after collection and until processing. Mineral samples were kept on ice until submittal to the laboratory for analysis.

A quality control and quality assurance program was conducted using blind split and spiked samples. Blind split samples were prepared at a ten percent frequency, and half of the blind splits were spiked with known concentrations of constituents to be analyzed in order to evaluate laboratory analytical recoveries. All reported results fell within the quality assurance tolerance guidelines outlined in Table 4.

The Regional Board monitoring program for the San Joaquin River began in May of 1985 and continued through WY 95. The focus of this report is to summarize selenium, boron and EC data collected at each site during WYs 86-95, due to their potential adverse effects on waterfowl and agriculture. Results for other constituents is available in annual data reports.

All samples were collected as grab samples within six feet of the bank. As such, these samples represent a snapshot concentration at a particular location and not a continuous measurement of overall concentration.

---

[1] Electrical conductivity values reported in the Appendices are laboratory EC values.

Table 3. Monitoring Sites, Sampling Frequencies, and Parameters Measured During Water Year 1995.

Site Code	Site Description	Frequency and Parameters Measured													
		Temp	pH	EC	Se	Mo	Cr	Cu	Ni	Pb	Zn	B	Part Min	Full Min	Sigma
MER555	Almond Drive Drain	M	M	M	Q								Q		
MER502	Charleston Drain	W	W	W	W	Q						W	M		
MER504	Hamburg Drain	W	W	W	W	Q						W	M		
MER505	Camp 13 Drain	M	M	M	M								M		
MER510	CCID Main @ Russell	M	M	M	Q								Q		
MER556	Main (Firebaugh) Drain @ Russell	W	W	W	W	Q						W	M		a
MER501	Panoche Drain	W	W	W	W	Q						W	M		a
MER506	Agatha Canal @ Mallard Rd	M	M	M	M								M		
MER509	Rice Drain @ Mallard Rd	M	M	M	Q								Q		
MER521	Boundary Drain	M	M	M	Q								Q		
MER519	Santa Fe Canal @ Henry Miller Rd	M	M	M	M								M		
MER532	San Luis Canal @ Henry Miller Rd	M	M	M	M								M		
MER527	San Luis Canal @ HWY 152	Q	Q	Q	Q								Q		
MER548	Porter-Blake Bypass (if in use)	M	M	M	M								M		
MER534*	San Luis Drain @ HWY 152	W	W	W	W							W			
MER537	San Luis Spillway Ditch @ Santa Fe	M	M	M	Q								Q		
MER528	Salt Slough @ Hereford	M	M	M	Q								Q		
MER536	Mud Slough upstream of SLD	Q	Q	Q	Q								Q		
MER535	San Luis Drain @ Terminus	Q	Q	Q	Q								Q		
MER542	Mud Slough @ San Luis Drain	W	W	W	W	Q	Q	Q	Q	Q	Q	W	M		a
MER531	Salt Slough @ Lander	W	W	W	W	Q	Q	Q	Q	Q	Q	W	M		a
MER522	SJR @ Lander Ave	W	W	W	M	Q	Q	Q	Q	Q	Q		M		
MER538	SJR @ Fremont Ford	W	W	W	W							W	M		
MER554	Los Banos Cr @ Hwy 140	M	M	M	Q								Q		
MER551	Mud Slough @ Newman Gun Club	M	M	M	M								M		
STC512	SJR @ Hills Ferry	W	W	W	W	Q	M	M	M	M	M	W	M	Q	
STC504	SJR @ Crows Landing (Evidence)	W	W	W	W	Q	M	M	M	M	M	W	M	Q	b
STC507	SJR @ Patterson	W	W	W	W							W	M		
STC510	SJR @ Maze Blvd	W	W	W	W							W	M		
SJC501	SJR @ Airport Way	W	W	W	W	Q	Q	Q	Q	Q	Q	W	M		

W = weekly
M = monthly
Q = quarterly (October, January, April, and July)
Part Min = B, Cl, SO4, and Hardness
Full Min = B, Ca, Mg, Na, K, Cl, SO4, HCO3, CO3, Hardness, Alkalinity, TDS, EC, pH
* = Sampling Discontinued 2-23-95

a = 4-day composite sample for Se and B
b = daily composite sample for Se and B

TABLE 4. Quality Assurance Tolerance Guidelines Used in the Regional Water Quality Control Board Agricultural Drainage Monitoring Program.

Constituent	Recovery Range at Low Levels (μg/L)*	Acceptable Split/ Spike Recovery Range
Copper	1-20 +/- 5	> 20 70-130%
Chromium	1-20 +/- 5	> 20 70-130%
Lead	5-25 +/- 8	> 25 60-140%
Molybdenum	1	90-110%
Nickel	5-25 +/- 6	>25 65-135%
Selenium	0.4	90-110%
Zinc	1-20 +/- 6	> 20 70-130%
Boron	50	85-115%
Chloride	5000	85-115%

* For certain constituents, recovery is expressed as an absolute value rather than a percentage at low levels. For example, if the result of copper analysis for a particular sample is 10 μg/L, a duplicate analysis must fall between 5 μg/L and 15 μg/L. If the sample is greater than 20 μg/L, recovery is expressed as a percent and must be between 70 and 130%. If a recovery range is not shown at low levels, the detection limit is given.

HYDROLOGY

GENERAL

The San Joaquin River is the principal drainage artery of the San Joaquin Valley. Major features of the San Joaquin River Basin are depicted in Figure 1. The river flows westward from the Sierra Nevada Range and turns sharply north at Mendota Pool near the town of Mendota, and drains into Suisun Bay via the San Joaquin-Sacramento River Delta. The river forms a broad flood plain as it turns northward, for a distance of approximately 50 miles until the river is narrowed by the constrictions of the Merced River and Orestimba Creek alluvial fans. These alluvial fans also form the northern boundary of the Grassland Watershed, a sub-basin of the San Joaquin River watershed that lies on the west side of the river. The principal drainage arteries for the Grassland Watershed are Mud Slough (north) and Salt Slough. Both sloughs discharge to the San Joaquin River near the northern boundary of the watershed. Flows from the east side of the river basin to the San Joaquin River are dominated by discharges from the Merced, Tuolumne, and Stanislaus Rivers. Flows from the west side of the river basin are dominated by agricultural return flows since Westside streams receive no snowmelt to maintain their flows and most go dry during the summer months.

The San Joaquin River Basin has undergone dramatic changes in hydrology and water quality in the past century due to agricultural development and alteration of the natural hydrology. In its pristine state, portions of the watershed were subject to annual flooding by the San Joaquin River followed by drainage, which created a landscape of seasonal and permanent wetlands and upland grassland. With the expansion of agriculture, increased levels of flood control and water diversion were implemented in the basin, which culminated with the Central Valley Project (CVP) in 1951. Some of the principal elements of this project that affect the Grassland Watershed and Lower San Joaquin River, include Friant Dam, the Delta Mendota Canal, Friant-Kern Canal, and Eastside Bypass. Impacts of the CVP on the River Basin included:

- less frequent annual flooding by the San Joaquin River;
- loss of natural flows from segments of the lower San Joaquin River, primarily, from the Mendota Pool to the confluence with the Merced River;
- elimination of flows from segments of the San Joaquin River upstream of the Mendota Pool;
- introduction of poorer quality water (higher salinity) imported from the Delta to the Grassland Watershed, to replace that lost through diversion of the upper San Joaquin River flows;
- more intensive irrigation of agricultural land in the western portion of the watershed.

In addition to the CVP, flood control projects were also completed in the eastern San Joaquin Valley to reduce flooding from the principal eastern streams that previously entered the Grassland Watershed and San Joaquin River. The reduction of flooding in the watershed by the CVP and other flood control projects removed the primary source of natural flow in the lower San Joaquin River and in water bodies contained within the Grassland Watershed.

Concurrent with the development of flood control projects, there was also internal development of the hydrologic infrastructure to improve water distribution within the Grassland Watershed. This development included construction of new channels, and modification (channelization) of existing natural channels. In addition, constructed facilities, modified natural channels and existing natural channels were interconnected via hydraulic structures (e.g. bypasses, gates, weirs, etc.) for the purpose of delivering water supplies to agricultural lands and artificially maintained wetlands and to convey surplus water to the San Joaquin River. In short, hydrology in the Grassland Watershed became managed, rarely responding to natural events such as precipitation runoff (CVRWQCB, 1996 draft).

Presently, the principal land uses in the Grassland Watershed are agriculture and wetlands. These activities are maintained by water from the Sacramento-San Joaquin Delta imported via the Delta Mendota Canal. This water replaced better quality (low salinity, alkalinity, and turbidity) supplies that were originally diverted from the San Joaquin River. Water diversion and flood control projects upstream on the San Joaquin River reduced the annual flooding in the lower basin including the Grassland Watershed. These floods were a major source of flow for Mud Slough (north) and Salt Slough, the principal drainage arteries of the Grassland Watershed. The former flood flows originated primarily in the Sierra Nevada and were characterized by good water quality (low salinity) due to the nature of the climate (humid with snowpack) and geology (primarily granitic) of the Sierra Nevada.

Prior to the CVP, flow and salinity within the Grassland Watershed varied widely depending on the season and on the runoff conditions of the particular water year, with seasonal flow in the sloughs governed by seasonal precipitation and runoff patterns of both the eastern side of the Diablo Range and the western side of the Sierra Nevada. During above normal runoff years, peak average monthly flow in Salt Slough was 1,550 cubic feet per second (cfs) and 3,800 cfs in Mud Slough (north). During below normal runoff years, average monthly flow in Salt Slough and Mud Slough (north) would remain below 100 cfs and 10 cfs, respectively. Mud Slough (north) would also be dry or nearly dry during portions of the year regardless of the runoff conditions (CVRWQCB, 1996 draft).

Following implementation of the CVP, flow and salinity in the Grassland Watershed was moderated and not subject to the wide fluctuations observed prior to the project. Instead, flow patterns reflected the surrounding land uses (agricultural and wetland), the management of irrigation and drainage, and the management of water supplies and wastewater.

As a result of the introduction of water supplies from the Delta Mendota Canal to the San Joaquin River Basin in the 1940s and 1950s, more intensive irrigated agricultural production developed on soils derived from the west side alluvial fans. The west side of the valley historically contained natural sinks and areas of high groundwater. Subsurface drainage was needed to maintain productivity in areas with high groundwater and poor drainage. Subsurface drainage from areas within the Grassland Watershed contain elevated selenium and boron concentrations due to leaching of these naturally occurring salts from the soil. The subsurface drainage discharge within the Grassland Watershed, blends with other water sources and eventually makes its way through Mud Slough (north) and/or Salt Slough until ultimately discharging to the San Joaquin River. Drainage flows can readily be switched between the two sloughs through a series of diversion structures so that either slough is able to carry the runoff. These subsurface drainage flows and other irrigation return flows dominate the flow and quality of discharges from the Grassland Watershed.

Currently, flow in the San Joaquin River depends, primarily, on scheduled releases from a series of upstream reservoirs, agricultural return flows, and groundwater seepage. Seasonal impacts may also occur from storm water runoff and wetland releases. Discharges from three major river systems, the Merced, Tuolumne, and Stanislaus Rivers, continue to dominate flow and quality of discharges from the east side of the lower San Joaquin River Basin. The major dams controlling these eastside discharges include New Exchequer Dam on the Merced River, New Don Pedro Dam on the Tuolumne River, and New Melones Dam on the Stanislaus River.

San Joaquin River flow and quality is also impacted by the fact that its headwaters are controlled by Friant Dam. Friant Dam, which created Millerton Lake in 1942, was built as a combination flood control and water conservation structure. Roughly 1,650 square miles drain into Millerton Lake which has a gross storage capacity of 520,000 acre-feet. Major releases from Millerton Lake to the San Joaquin River are rare in occurrence and normally coincide with above normal runoff. During a normal runoff year, annual discharge from the reservoir to the San Joaquin River is usually limited to 100,000 acre-ft. During a flood year (such as 1995), releases may reach up to 1,500,000 acre-ft. The major releases directly reflect the flood control properties of the structure and will normally occur in a relatively short duration in response to major storm events and spring snow melt (normally between March and June). Most of the discharge from Millerton Lake, is diverted south into the Friant-Kern Canal (part of the CVP) and out of the San Joaquin River Basin. During most years, discharge is inadequate to maintain flow in the river channel downstream to Mendota Pool. During the irrigation season, the San Joaquin River is generally dry upstream of the Mendota Pool and only carries subsurface inflows and minor drainage between the Pool and Salt Slough.

In addition to the four reservoirs which discharge to the main stem of the Lower San Joaquin River, inflows may also occur during high runoff years from the Kings River via the Fresno Slough and the Mendota Pool. The Kings River has a drainage area of 1,542 square miles above Pine Flat Reservoir which regulates runoff to the river. The Kings River normally flows south into the Tulare Lake Basin and does not directly discharge to the San Joaquin River. However, during major runoff events, the Kings River will flow north through the Fresno Slough to the Mendota Pool.

The Mendota Pool is a shallow impoundment that receives water from the Delta-Mendota Canal, Fresno Slough and the San Joaquin River. The Pool is used as a distribution point of CVP water received via the Delta-Mendota Canal to area water agencies and individual land owners. Total flows are gauged as releases from the Mendota Dam. Water released from the Pool passes through irrigated lands west of the San Joaquin River and eventually discharges to the river via Mud Slough (north) and/or Salt Slough or can be discharged directly to the San Joaquin River upstream of Lander Avenue.

WATER YEARS 1986 THROUGH 1995

A water year (WY) extends from 1 October of one year to 30 September of the following year. Since the water quality monitoring for this program began in May 1985, a complete water year of data is not available until WY 86. Although water quality information between May 1985 and October 1985 is included in the Appendices, the water year summaries presented in this report focus on the ten years of complete records: WYs 86 through 95.

The San Joaquin River Index, as described in the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (SWRCB, 1995) is used to classify water year type in the river basin based on total runoff. The ten year period of record under review contained a wide variety of runoff year types, including two of the three highest runoff years since record keeping began in 1906, and six consecutive years of drought. Based on the San Joaquin River Index, WY 86 was a wet year and WYs 87 through 92 were classified as critically dry water years. Water Year 93 was the first wet water year following the six consecutive critically dry years, with WY 94 returning to critically dry water year conditions. Water Year 95 was classified as a wet year with the San Joaquin River unimpaired runoff roughly 214% of average. The high runoff made WY 95 the third highest runoff year since 1906, superseded only by WYs 1986 and 1906 (DWR, 1995).

Table 5 presents the precipitation recorded at Friant Dam during WY 86 through WY 95. Figure 3 compares the precipitation recorded at Friant Dam and the measured flow traveling downstream in the San Joaquin River at Lander Avenue, Patterson and Vernalis. Except for periods of extremely high precipitation in the Friant watershed, runoff in the San Joaquin River does not necessarily correspond to the precipitation pattern. The heaviest rainfall tends to occur from November through March and peak releases from the reservoir tend to occur in March. This pattern is consistent with the highly managed hydrology within the watershed. The peak flows in February and March seen in the Lower San Joaquin River are due to Friant releases and correspond to designed flood control operating measures. Impact to the Lower San Joaquin River is minimal after March or April because most of the water released is diverted to the Friant-Kern Canal for agricultural irrigation along the east side of the San Joaquin Valley.

Figure 3. Monthly Precipitation at Friant Dam as Related to Monthly Flow in the San Joaquin River

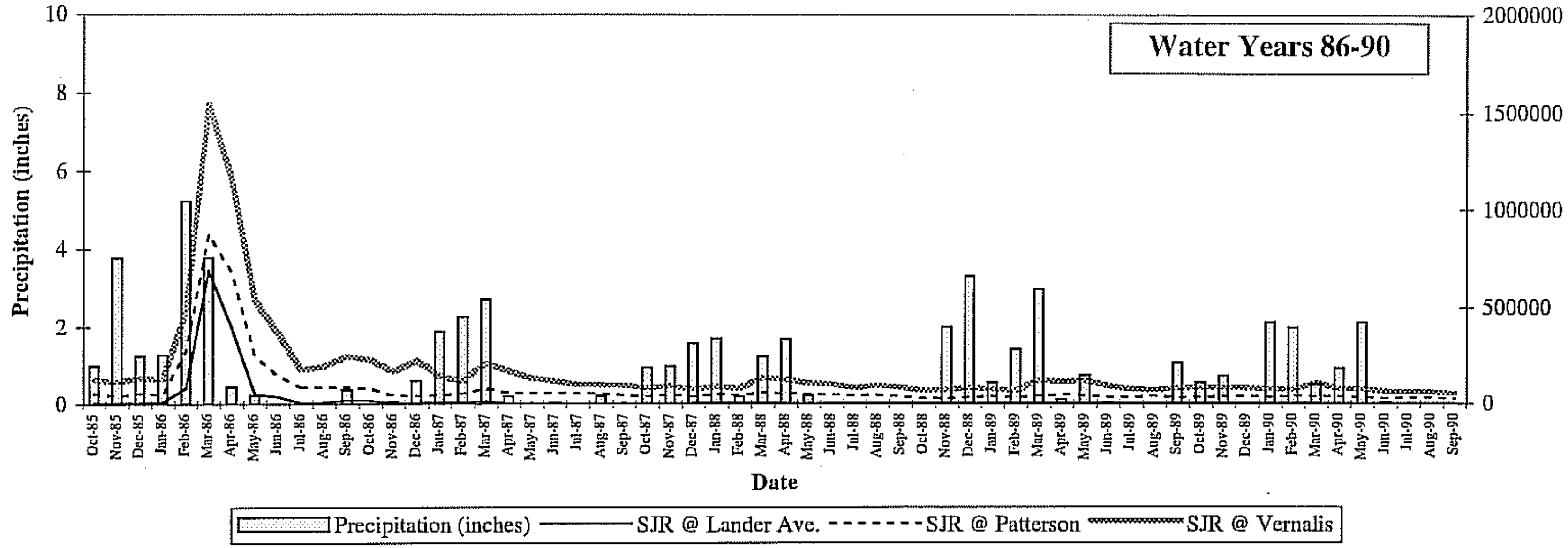


Figure 3 continued:

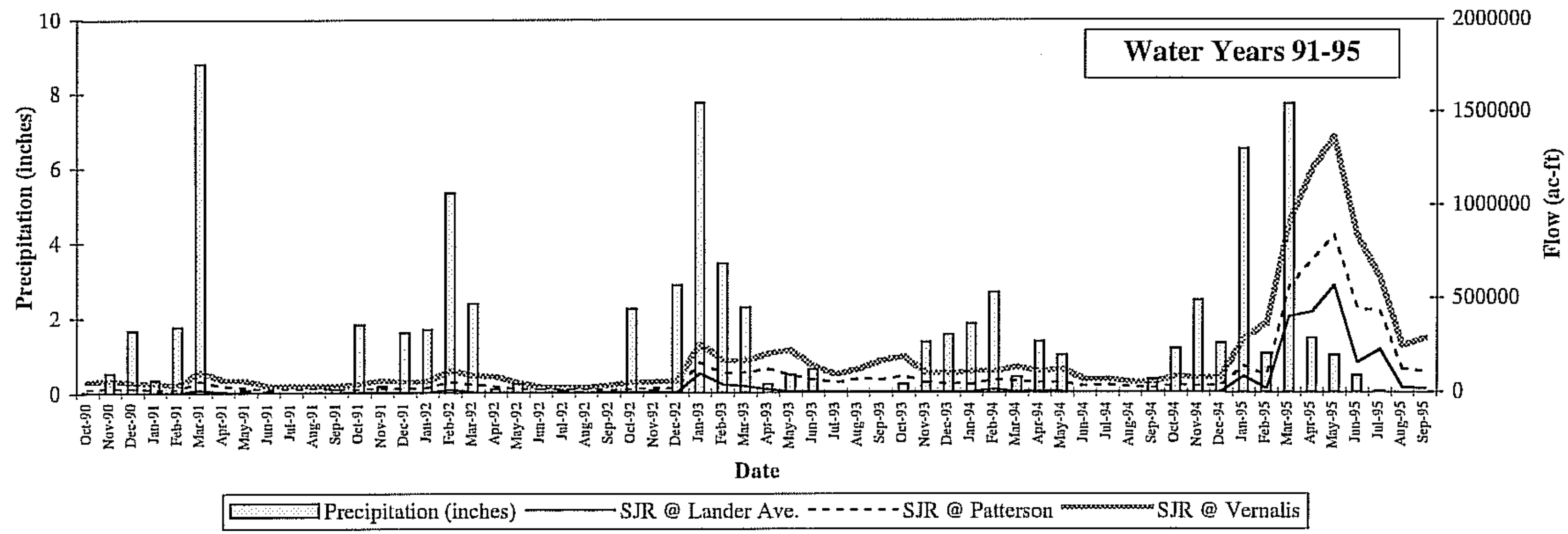


Table 5. Ten Year Historic Precipitation Record by Month and Water Year Measured at Friant Dam on the San Joaquin River: WYs 86-95

	Precipitation in Inches										Monthly Precipitation (inches)		
Month	WY86	WY87	WY88	WY89	WY90	WY91	WY92	WY93	WY94	WY95	Min	Max	Mean
Oct	0.98	0	0.93	0	0.55	0.01	1.79	2.21	0.21	1.15	0	2.21	0.78
Nov	3.77	0.04	0.96	1.98	0.72	0.52	0.16	0.05	1.32	2.44	0.04	3.77	1.20
Dec	1.24	0.59	1.57	3.31	0	1.65	1.59	2.84	1.52	1.28	0	3.31	1.56
Jan	1.27	1.86	1.70	0.55	2.11	0.33	1.66	7.72	1.81	6.48	0.33	7.72	2.55
Feb	5.22	2.25	0.18	1.41	1.97	1.75	5.30	3.42	2.65	1.01	0.18	5.3	2.52
Mar	3.78	2.70	1.22	2.97	0.51	8.79	2.36	2.25	0.39	7.69	0.39	8.79	3.27
Apr	0.44	0.18	1.67	0.11	0.91	0.01	0.08	0.20	1.34	1.42	0.01	1.67	0.64
May	0.22	0	0.22	0.73	2.11	0.06	0.22	0.45	0.97	0.95	0	2.11	0.59
Jun	0	0.01	0.02	0.03	0.04	0.03	0	0.60	0	0.42	0	0.6	0.12
Jul	0	0	0	0	0	0	0.04	0	0	0.02	0	0.04	0.01
Aug	0	0.20	0	0.01	0	0	0	0	0	0	0	0.2	0.02
Sep	0.36	0	0	1.05	0	0.08	0	0	0.33	0	0	1.05	0.18
Max:	5.22	2.70	1.70	3.31	2.11	8.79	5.30	7.72	2.65	7.69			
Mean:	1.44	0.65	0.71	1.01	0.74	1.10	1.10	1.65	0.88	1.91			
Net Sum:	17.3	7.83	8.47	12.2	8.92	13.2	13.2	19.7	10.5	22.9			

WY = Water Year (1 October through 30 September)

This pattern occurred during WY 86 and WY 95, the second and third highest runoff years on record, respectively (since 1906). A total of 17.28 inches of rain fell during WY 86 with 59% of the total falling from January to March. Precipitation peaked in March, with a monthly total of 5.22 inches. During WY 95, 22.86 inches of rain fell, with 66% of the total precipitation occurring from January to March. As in WY 86, precipitation peaked in March at 7.69 inches. Between WY 86 and WY 95, the average precipitation in March was 3.16 inches.

In response to the record rainfalls, record releases also occurred from the other major reservoirs in the river basin. During WY 86, Friant Dam released 981,160 acre-feet to the San Joaquin River. Roughly 95% of those releases occurred between February and May with a peak release of 416,140 acre-feet occurring in March. McSwain Dam, which regulates flows to the Merced River, had a peak release of 213,456 acre-feet in April and a total WY 86 release of 1,098,158 acre-ft (86% of which occurred between March and August). In addition, during WY 86, the Kings River flowed north from February to July, contributing a total of 669,790 acre-feet to the San Joaquin River via the Fresno Slough and Mendota Pool.

During WY 95, Friant Dam discharged 1,585,540 acre-feet to the San Joaquin River with 66% of the releases occurring from February to May. The peak release of 451,730 acre-feet occurred in May. The Kings River also contributed 586,500 acre-feet to the San Joaquin River, during WY 95, via the Fresno Slough, primarily between March and August. McSwain Dam actually overtopped during the spring of 1995, and released water via the hydroelectric turbines and ungated spillway. This type of release is a rare occurrence, with the only similar event occurring during 1982-1983 (Tom Stevens, U.S. Bureau of Reclamation, personal communication, 1996). McSwain Dam discharged 1,629,646 acre-ft during WY 95 to the Merced River with above normal releases occurring from March to September. The peak release occurred in May 1995 (297,313 acre-feet).

Flow in the San Joaquin River reflected both the unusual precipitation events of WYs 86 and 95 and the record reservoir releases. WYs 86 and 95 had the highest total flows in the San Joaquin River for the ten-year study. Flows at Vernalis totaled 5,226,038 acre-feet during WY86 and 6,299,190 acre-feet during WY 95. These total annual flows compare to an average annual flow of 203,733 acre-feet during the six consecutive years of drought (WY 87 through WY 92). Table 6 lists the mean, minimum, maximum and total flows during each water year for selected San Joaquin River sites, monitored during WYs 86 through 95.

During the low flow periods, discharges from Mud Slough (north) and Salt Slough can have a major effect on both San Joaquin River quality and quantity. To illustrate this point, the combined total flows in the sloughs were compared to the total flows in the river at Hills Ferry Road and Vernalis from WY 86 through WY 95 (Figures 4 and 5). Hills Ferry Road represents the first monitoring site downstream of the Mud and Salt Slough inflows to the San Joaquin River, and Vernalis represents the total flow in the San Joaquin River upstream of the Sacramento-San Joaquin Delta. Flow data is only available from a Hills Ferry Road gage through WY 93. Flows at Hills Ferry Road for WYs 94 and 95 were estimated by subtraction of Merced River flows from San Joaquin River at Patterson flows and multiplying by a factor of 1.09. The factor was based on the average of the previous eight years of available records. Since the Hills Ferry Road monitoring location is upstream of the inflow from the Merced River, and the flow gage is downstream of the inflow, Merced River flows were subtracted from the available and estimated Hills Ferry Road flow records total to determine a rough estimate of San Joaquin River flow upstream of the Merced River. The combined total flow from the sloughs were then compared to the river flow seen at Hills Ferry Road. The combined total flows in the sloughs contributed an average of 64% of the total flow seen at Hills Ferry Road upstream of the Merced River between WYs 86 and 95, with a maximum of 82% during WY 89. (Based on estimated values, the sloughs provided 114% of the flow at Hill Ferry Road in WY 94). The combined flow contributed an average of 13% to the total flow at Vernalis during WYs 86 through 95, with a maximum of 21% during WY 90.

APPLICABLE WATER QUALITY OBJECTIVES

Between WY 86 and WY 95, a variety of selenium and boron water quality objectives have been in place in the San Joaquin Valley. When the water quality monitoring program was established in 1985, selenium and boron water quality objectives had not yet been adopted by the Regional Board for the study area. During that time period, selenium concentrations were compared to the U.S. Environmental Protection Agency (USEPA) Water Quality Criteria for the Protection of Beneficial Uses. The USEPA ambient water quality criteria for protection of aquatic life for selenium (based on a 4-day average) was 5μg/L. A USEPA ambient water quality criteria for boron was not available.

In 1988, the Regional Board adopted selenium, boron, and molybdenum water quality objectives for the Lower San Joaquin River from Sack Dam to Vernalis, for Mud Slough (north) and Salt Slough, and for wetland water supplies (Resolution #88-195). These water quality objectives were approved by the State Water Resources Control Board in 1989, through Resolution #89-88. This Basin Plan[1] amendment was recognized as a first step in reducing selenium concentrations in water bodies within the San Joaquin River Basin. In order to achieve the reductions, milestones were set for the elements of concern (selenium, boron, and molybdenum), to assess the progress towards meeting the established objectives. The final objectives are listed in Table 7.

[1] Basin Plan = Water Quality Control Plan for the Sacramento River and San Joaquin River Basins.

Table 6. Monthly and Total Annual Flow (acre-feet) at Select San Joaquin River Basin Monitoring Sites: WYs 86-95

Water Year	Flows in Acre-feet					
	SJR @ Lander	Mud and Salt Sloughs	SJR @ Hills Ferry*	Merced River	SJR @ Patterson	SJR @ Vernalis
1986						
Monthly Min:	2,293 (Nov)	10,200 (Nov)	26,966 (Nov)	12,970(Jan)	39,693 (Nov)	114,756 (Nov)
Monthly Max:	688,998 (Mar)	43,720 (Mar)	850,370 (Mar)	182,200(Mar)	875,831 (Mar)	1,539,006 (Mar)
Monthly Mean:	109,072	21,355	198,399	51,943	223,064	435,503
Annual Total:	1,308,869	284,316	2,380,786	623,310	2,676,764	5,226,038
1987						
Monthly Min:	989 (Jul)	11,090 (Dec)	25,924 (Sept)	7,620(Jul)	39,584 (Dec)	9,498 (Sept)
Monthly Max:	14,204 (Oct)	37,230 (Mar)	68,595 (Mar)	27,790(Oct)	79,226 (Mar)	22,9988 (Oct)
Monthly Mean:	4,274	19,487	40,540	13,261	55,178	151,101
Annual Total:	51,290	233,843	486,476	159,130	662,135	1,813,216
1988						
Monthly Min:	331 (Sept)	8,630 (Dec)	20,885 (Oct)	2,130(Sep)	35,737 (Sept)	78,566 (Dec)
Monthly Max:	4,314 (Jan)	32,500 (Mar)	49,439 (Mar)	15,280(Jan)	58,498 (Mar)	137,739 (Mar)
Monthly Mean:	1,662	19,205	33,027	9,205	45,784	97,339
Annual Total:	19,939	230,843	396,323	110,460	549,412	1,168,066
1989						
Monthly Min:	85 (Nov)	11,450 (Jan)	20,481 (Nov)	1,470(Aug)	28,882 (Oct)	68,512 (Feb)
Monthly Max:	4,342 (Mar)	23,570 (Aug)	44,621 (Apr)	18,960(Mar)	48,165 (Apr)	124,373 (Mar)
Monthly Mean:	1,072	17,616	29,693	8,298	36,533	88,223
Annual Total:	12,865	211,393	356,317	99,580	438,398	1,058,670
1990						
Monthly Min:	29 (Sept)	11,421 (Jun)	13,401 (Sept)	1,170(Aug)	23,869 (Sept)	52,105 (Sept)
Monthly Max:	1,734 (Mar)	20,680 (Mar)	37,715 (Mar)	13,590(Feb)	38,940 (Feb)	108,212 (Mar)
Monthly Mean:	495	16,221	28,167	7,435	33,680	76,294
Annual Total:	5,937	194,656	338,004	89,220	404,163	915,524
1991						
Monthly Min:	8 (Dec)	4,109 (Jan)	8,114 (Jun)	371(Jul)	16,226 (Feb)	33,035 (Aug)
Monthly Max:	15,580 (Mar)	20,170 (Mar)	59,329 (Mar)	19,676(Mar)	62,642 (Mar)	109,355 (Mar)
Monthly Mean:	1,547	8,514	17,809	5,938	24,269	54,746
Annual Total:	18,556	102,162	213,711	71,256	291,223	656,954
1992						
Monthly Min:	27 (Sept)	2,626 (Sept)	6,322 (Sept)	2,063(Jul)	13,742 (Sept)	27,461 (Jul)
Monthly Max:	16,570 (Feb)	17,600 (Mar)	51,054 (Feb)	17,795(Feb)	57,124 (Feb)	120,233 (Feb)
Monthly Mean:	1,999	7,119	19,663	8,662	25,346	58,348
Annual Total:	23,989	85,428	235,961	103,943	304,151	700,177
1993						
Monthly Min:	20 (Nov)	2,746 (Oct)	11,866 (Oct)	10,635(Oct)	15,282 (Oct)	52,171 (Jul)
Monthly Max:	100,400 (Jan)	23,160 (Jan)	140,515 (Jan)	60,270(Apr)	15,778 (Jun)	253,269 (Jan)
Monthly Mean:	16,337	13,996	62,577	30,226	74,269	141,871
Annual Total:	196,039	167,955	750,929	362,708	891,230	1,702,457
1994						
Monthly Min:	65 (Sept)	7,550 (Sept)	—	4,880(Sep)	22,957 (Sept)	51,699 (Oct)
Monthly Max:	16,760 (Feb)	25,720 (Mar)	—	51,914(Oct)	86,078 (Oct)	186,918 (Jan)
Monthly Mean:	2,770	15,296	31,461	17,995	46,858	101,615
Annual Total:	33,245	183,546	377,536	215,938	562,301	1,219,382
1995						
Monthly Min:	99 (Oct)	8,189 (Oct)	—	12,780(Dec)	30,939 (Nov)	76,603 (Sept)
Monthly Max:	566,700 (May)	45,967 (Mar)	—	226,600(May)	831,075 (May)	1,363,907 (Oct)
Monthly Mean:	158,188	21,981	222,987	87,428	292,003	524,933
Annual Total:	1,898,261	263,769	2,675,845	1,049,130	3,504,034	6,299,190

* Gaged flows only available through WY93. Estimated flows calculated for WYs 94 and 95 using the following equation:

1.09(SJR at Patterson flow - Merced River flow)

The 1.09 factor is based on the average for the eight years of available flow records.

WY = Water Year (1 October through 30 September)

Figure 4. Annual Flows in Mud and Salt Sloughs Combined, and in Two Sites on the San Joaquin River: WYs 86-95

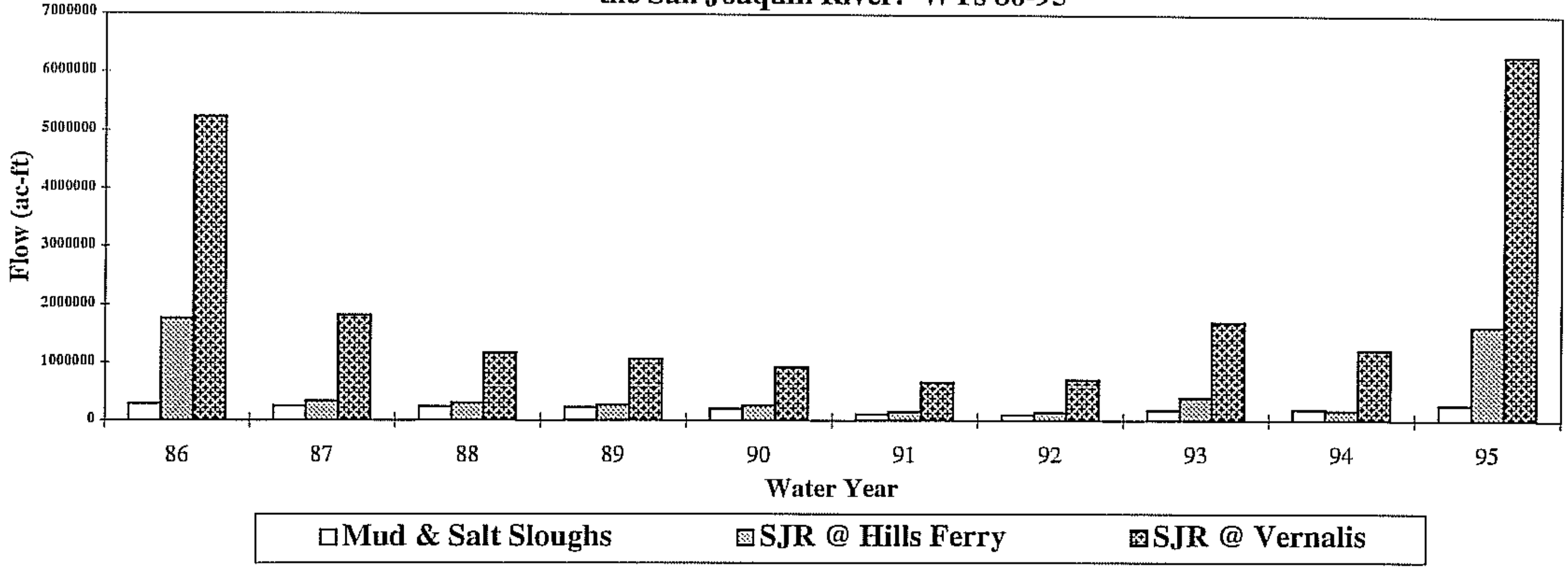
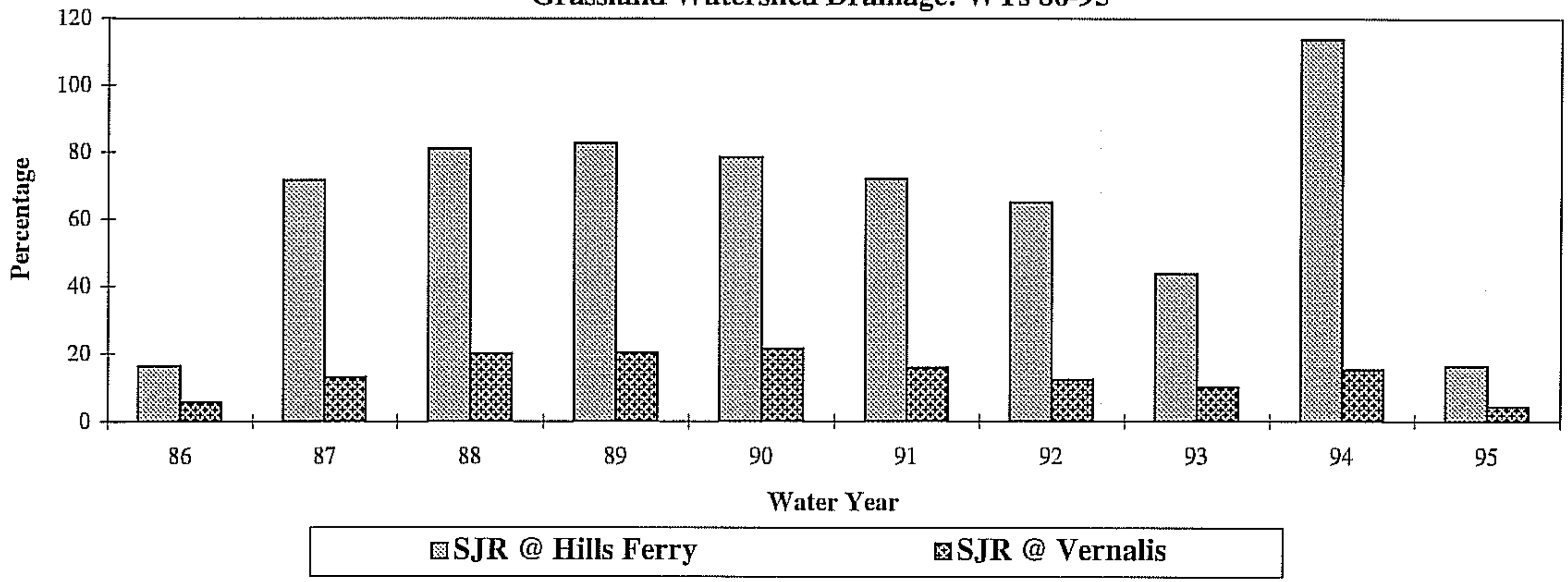


Figure 5. Percentage of San Joaquin River Flow at Two Downstream Sites Made Up of Grassland Watershed Drainage: WYs 86-95



Note that flow values for the San Joaquin River at Hills Ferry are estimates for WYs 94 and 95.

TABLE 7

Water Quality Objectives as Adopted in 1988 by the
California Regional Water Quality Control Board, Central Valley Region
for the San Joaquin River Basin (5C)

Constituent	Water Quality Objectives (WQO)		Compliance Date
San Joaquin River, mouth of the Merced River to Vernalis (Delta Inflow)			
Selenium	5 μg/l monthly mean	12 μg/l max.	Oct. 1, 1991
	8 μg/l monthly mean (critical year only)		Oct. 1, 1991
Molybdenum	10 μg/l monthly mean	15 μg/l max.	Jan. 1, 1990
Boron	0.8 mg/l monthly mean (15 March-15 Sept)	2.0 mg/l max.	Oct. 1, 1991
	1.0 mg/l monthly mean (16 Sept-14 March)	2.6 mg/l max.	Oct. 1, 1991
	1.3 mg/l monthly mean (critical year only)		Oct. 1, 1991
Salt Slough, Mud Slough (north), San Joaquin River, Sack Dam to mouth of the Merced River			
Selenium	10 μg/l monthly mean	26 μg/l max.	Oct. 1, 1993
Molybdenum	19 μg/l monthly mean	50 μg/l max.	Jan. 1, 1990
Boron	2.0 mg/l monthly mean (15 March-15 Sept)	5.8 mg/l max.	Oct. 1, 1993
Grassland Water District, San Luis National Wildlife Refuge, and Los Banos State Wildlife Area (Measured in any water used by subject areas for waterfowl habitat)			
Selenium	2 μg/L monthly mean		

The San Joaquin River Index, as described in the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta (SWRCB, 1995) is used to classify water year type in the river basin based on total runoff.

The milestones and objectives adopted in 1988, recognized the highly managed hydrology of the study area and the immense impact that water supply could have on constituent concentrations. First, separate objectives were set for each major water body type. The most restrictive selenium objectives were set for wetland water supply (2 μg/L) to reflect the sensitivity of waterfowl to this element. Mud Slough (north) and Salt Slough received the least restrictive objectives because they are usually dominated by agricultural drainage water and they have lacked natural headwater flows since the advent of the Central Valley Project in 1951. The San Joaquin River was divided into two sections: Sack Dam to the mouth of the Merced River; and the mouth of the Merced River to Vernalis. The San Joaquin River upstream of the Merced River and downstream of the Salt Slough inflow is dominated by agricultural return flows and had less restrictive water quality objectives than the portion of the river downstream of the Merced River which is influenced by high quality East side tributary flows.

In addition, the objectives depended in part on the water-year type. During critical water years, slightly relaxed boron and selenium objectives were specified which reflected the lack of good quality dilution flows from excess tailwater and/or flows from the East side tributaries during low runoff years. During normal and above normal water-year types, more stringent objectives apply.

Boron water quality objectives were also specified by season. The beneficial use most restricted by elevated boron concentrations is agricultural supply; therefore, the boron objectives are more stringent during the irrigation season than during the period of winter storm flows.

On 22 December 1992, the USEPA promulgated the National Toxics Rule according to Section 303(c)(2)(B), of the Federal Clean Water Act. This promulgation included a more stringent selenium water quality criteria of 5 μg/L as a four-day average and a maximum criteria of 20 μg/L for Mud Slough (north), Salt Slough, and the San Joaquin River. The promulgation superseded all but the 12 μg/L maximum selenium objective adopted by the Regional Board for the San Joaquin River from the mouth of the Merced River to Vernalis, the 2 μg/L selenium objective adopted for wetland water supplies, and the boron and molybdenum objectives.

The promulgation led to confusion as to which selenium water quality objectives or criteria applied to the study area. Therefore, in May 1996, the Regional Board adopted a revised basin plan amendment (Resolution #96-147) which includes a compliance time schedule for meeting the criteria promulgated by the USEPA. Since the revised objectives were not in place between WY 86 and WY 95, they have not been discussed in detail in this report. However, a comparison of measured concentrations to the USEPA criteria is included in the discussion section.

DISCUSSION

Grassland Watershed: WYs 86-95

Mud Slough (north) and Salt Slough are the principal tributaries to the San Joaquin River that drain the Grassland Watershed and are described in detail in previous reports (Pierson *et al.*, 1989a and 1989b). Mud Slough (north) at the San Luis Drain and Salt Slough at the Lander Avenue Bridge are located near continuous flow monitoring stations operated by the U.S. Geologic Survey and were, therefore, made the principal stations in this water quality monitoring program. Both of these water bodies are effluent dominated and best represent the water quality of the drainage leaving the Grassland Watershed.

Imported salt, brought into the Grasslands Watershed with irrigation water, collects in the vadose zone of agricultural soils year around. When water supplies are available for deep pre-irrigation of agricultural land during the winter and early spring each year, these imported salts as well as salts and trace elements previously in the soil are effectively driven below the root zone and into on-farm subsurface drainage collector systems. This process is an attempt by area farmers to maintain a salt balance in the root zone of their crops. Similarly, salt imported into the Grassland Watershed with wetland supply water can collect in the soil of seasonal wetlands. This salt is mobilized when water is reapplied to dry wetlands.

Figures 6, 7 and 8 show a comparison of annual median electrical conductivity (EC), boron, and selenium concentration, respectively, in Mud Slough (north) and Salt Slough from WY 86 to 95. Table 8 lists the annual median constituent concentration for the Grassland Watershed canals and streams, monitored by the Regional Board, for each year during the 10-year period. Table 9 summarizes the median for all data collected for each site.

The median EC values within Mud Slough (north) fluctuated during the 10-year study while median EC values within Salt Slough steadily increased over the same period.

Annual median boron concentrations were consistently higher in Mud Slough (north) than Salt Slough until the trend was reversed in WY 93. Annual median boron concentrations in Salt Slough showed a steady increase over the 10-year study.

A relationship between EC and boron concentration is evident when comparing the median concentration trends for the values in Mud (north) and Salt Slough. Salt Slough median EC and boron trends both show steady, gradual increases over the 10-year study with a slight drop in WY 95. The peak annual median boron concentration and EC that occurred in Mud Slough (north) during WY 91, correspond to the lowest total flow (12,762 acre-feet) in the 10-year study.

This boron/EC relationship is not found when comparing median EC to median selenium concentration. Selenium is a naturally occurring element in some Grassland Watershed soils and is not present as a result of general wetland or agricultural irrigation practices as is the case with salts. The presence of a high selenium concentration in Mud Slough (north) and/or Salt Slough is an indicator of the presence of subsurface agricultural drainage from selenium enriched areas.

Annual median selenium concentration fluctuated in both sloughs during the 10-year study. Selenium concentration in Salt Slough followed a similar trend as boron and EC, increasing over the 10-year period with a slight decrease during WY 92. Mud Slough median selenium concentrations have remained low since 1988.

The annual fluctuation in overall median selenium concentration can be partly attributed to the hydrology of the area. Since the primary source of selenium is subsurface agricultural drainage from the 90,000 acre Drainage Problem Area (DPA), the presence of selenium reflects the presence of subsurface drainage. Between WYs 86 and 88, subsurface drainage was discharged alternately between the two sloughs. Beginning in WY 89, drainage district managers began to actively divert subsurface drainage to Salt Slough through the Porter-Blake Bypass. Without the subsurface drainage, selenium concentrations in Mud Slough remained low, typically below 2 μg/L while concentrations in Salt Slough stayed closer to 15 μg/L. A slight aberration to this pattern occurred in WY 90 when the drainage was diverted to Mud Slough during short periods in the spring and summer. The removal of subsurface agricultural drainage discharges from a water body, clearly corresponds to a decrease in selenium in that water body.

Figure 6. Annual Median Electrical Conductivity in Mud Slough (north) and Salt Slough: WYs 86-95

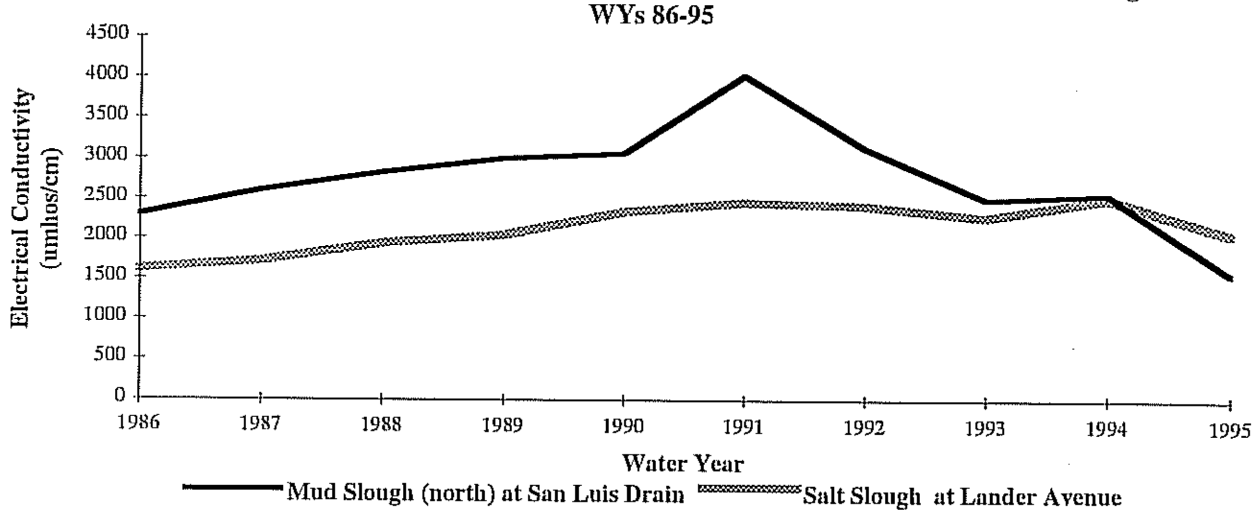


Figure 7. Annual Median Boron Concentration in Mud Slough (north) and Salt Slough: WYs 86-95

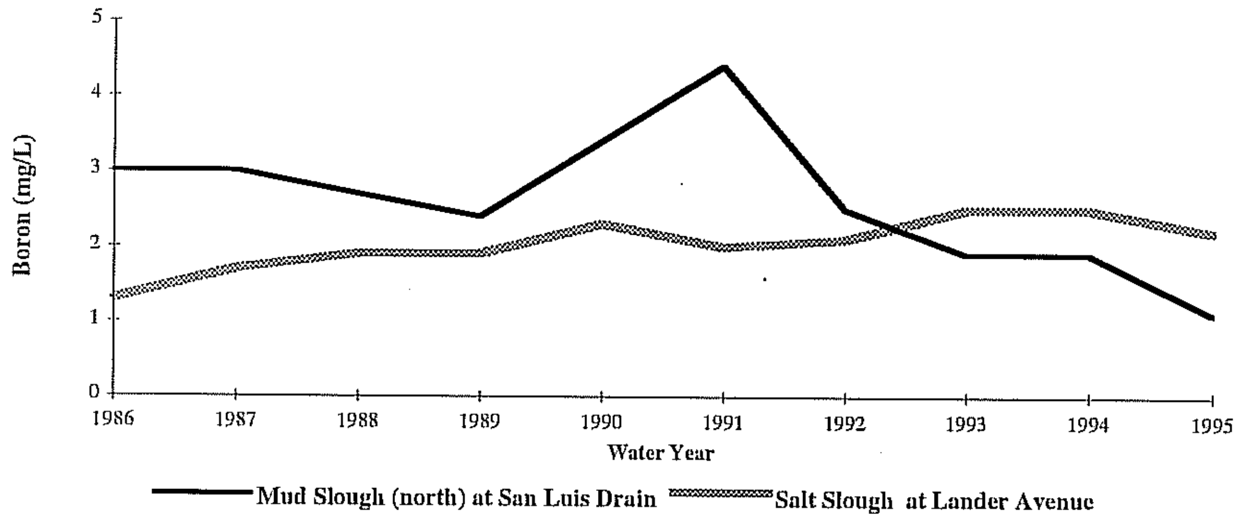


Figure 8. Annual Median Selenium Concentration in Mud Slough (north) and Salt Slough: WYs 86-95

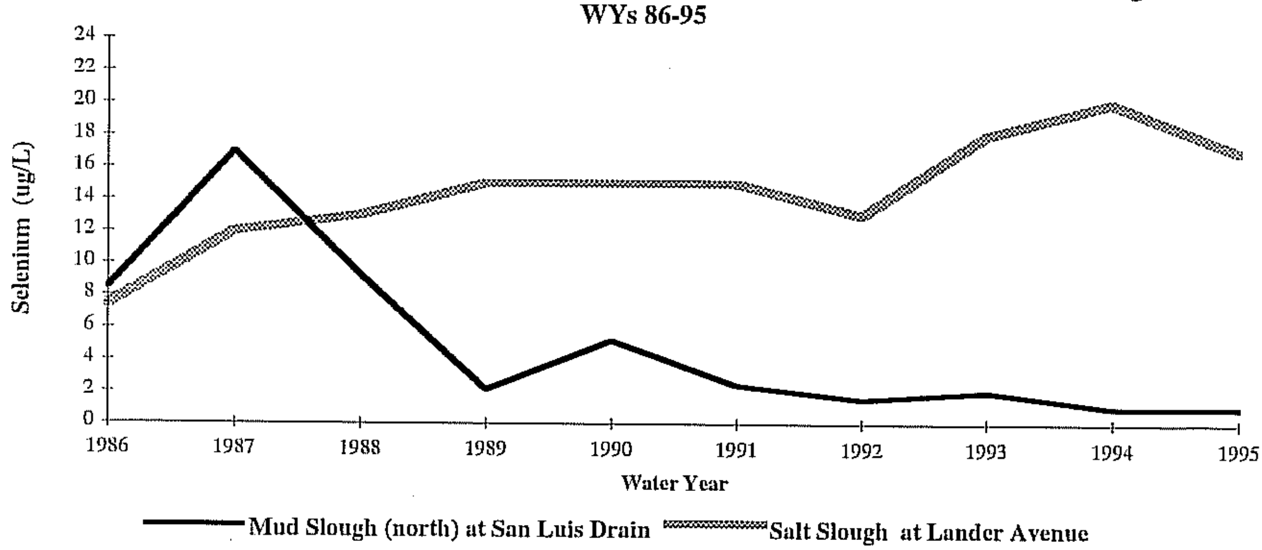


Table 8. Median Constituent Concentrations for Grassland Watershed Canals & Streams: Water Years 1986-1995.
(Data from James et al., 1988; Chilcott et. al., 1989; Westcot et al., 1990, 1991, 1992; Karkoski and Tucker, 1993; Chilcott et al., 1995; Vargas et al., 1995; and Steensen et al., 1996.)

Map ID†	Monitoring Site/ Constituent	Median Constituent Concentration for a Given Water Year and Type									
		1986 Wet	1987 Critical	1988 Critical	1989 Critical	1990 Critical	1991 Critical	1992 Critical	1993 Wet	1994 Critical	1995 Wet
I-1	Main (Firebaugh) Drain @ Russell Blvd.										
	EC (umhos/cm):	2700	2600	3000	2980	3400	3450	3700	3530	3550	3710
	Boron (mg/L):	3.5	3.4	3.6	3.9	4.6	4.6	5.2	5.1	4.5	4.2
	Selenium (ug/L):	46	42	49	49	52	52	59	52	61	65
I-2	Panoche Drain/O'Banion										
	EC (umhos/cm):	3400	4375	3650	4180	4550	4450	4870	4800	4840	4640
	Boron (mg/L):	5.8	7.8	6.4	6.5	7.5	7.5	8.0	7.7	8.0	7.6
	Selenium (ug/L):	56	47	54	69	72	64	82	76	88	84
I-3	Agatha Inlet (Mercy Springs)										
	EC (umhos/cm):	3300	3125	4150	3655	4910	3770	4470	4780	—	—
	Boron (mg/L):	7.2	7.0	8.6	7.6	8.4	6.4	7.4	8.4	—	—
	Selenium (ug/L):	14	6	7.9	6.7	7.9	4.7	7.8	41	—	—
I-4	Agatha Canal*										
	EC (umhos/cm):	3300	3305	3550	880	4040	4295	3440	3165	3570	1520
	Boron (mg/L):	5.6	5.6	5.6	0.36	6.6	6.6	5.6	5.4	5.9	0.64
	Selenium (ug/L):	44	38	39	2.9	26	53	31	23	14	4.4
I-5	Helm Canal										
	EC (umhos/cm):	840	—	—	—	—	—	—	—	—	—
	Boron (mg/L):	0.73	—	—	—	—	—	—	—	—	—
	Selenium (ug/L):	3	—	—	—	—	—	—	—	—	—
I-6	Hamburg Drain										
	EC (umhos/cm):	3250	3345	3600	5120	4740	5540	5090	5020	5320	4850
	Boron (mg/L):	4.0	3.7	4.1	5.7	5.4	5.6	5.2	6.3	5.9	5.3
	Selenium (ug/L):	51	58	56	95	84	99	86	76	88	70
I-7	Camp 13 Slough										
	EC (umhos/cm):	2950	2650	4400	3750	3440	3960	4130	4020	3960	2780
	Boron (mg/L):	3.9	3.7	6.2	5.2	4.9	5.5	5.5	6.2	5.8	2.6
	Selenium (ug/L):	43	43	43	59	54	55	64	56	58	32
I-8	Charleston Drain										
	EC (umhos/cm):	4500	3855	4450	4400	4350	4370	4283	4155	4540	4500
	Boron (mg/L):	4.7	4.2	4.5	3.8	3.7	4.2	4.3	4.2	4	4
	Selenium (ug/L):	93	79	71	66	69	60	66	70	78	63
I-9	Almond Drive Drain										
	EC (umhos/cm):	—	1925	2300	2160	1320	1415	1670	900	840	610
	Boron (mg/L):	—	2.1	2.1	2.2	0.91	1.0	1.5	0.40	0.58	0.32
	Selenium (ug/L):	—	4.8	4.6	3.7	2.3	2.9	2.2	1.9	2.1	1.7
I-10	Rice Drain										
	EC (umhos/cm):	3300	2500	2790	2745	3050	2640	3000	2250	2970	2640
	Boron (mg/L):	8.1	6.1	5.1	5.4	5.4	4.7	5.9	4.1	5.4	3.9
	Selenium (ug/L):	3.0	2.6	2.6	3.1	2.7	2.6	3.4	2.6	3.2	2.4
I-11	Boundary Drain										
	EC (umhos/cm):	1710	1250	1470	1435	1500	1420	1330	1040	1660	1500
	Boron (mg/L):	0.65	0.54	0.5	0.53	0.44	0.44	0.48	0.49	0.65	0.63
	Selenium (ug/L):	1	1.6	1.4	1	0.9	0.8	0.8	1.1	1.1	0.6
I-12	Salt Slough @ Hereford										
	EC (umhos/cm):	785	1000	1150	1070	1030	1045	1140	1060	1020	740
	Boron (mg/L):	0.33	0.39	0.38	0.36	0.30	0.30	0.37	0.35	0.33	0.2
	Selenium (ug/L):	1	1.4	1.2	1.2	0.6	0.9	1	0.8	0.8	0.7
I-13	Garzas Creek @ Hunt Road*										
	EC (umhos/cm):	800	800	—	—	—	—	—	—	—	—
	Boron (mg/L):	0.49	0.34	—	—	—	—	—	—	—	—
	Selenium (ug/L):	1	1.4	—	—	—	—	—	—	—	—
T-1	CCID Main Canal										
	EC (umhos/cm):	385	570	760	700	680	710	800	820	670	301
	Boron (mg/L):	0.21	0.28	0.29	0.26	0.32	0.27	0.38	0.35	0.37	0.25
	Selenium (ug/L):	1.3	2.2	1.7	1.7	2.3	1.5	2	1.4	1.7	1.4

† Refers to Figure 1A in Appendix

Table 8. Median Constituent Concentrations for Grassland Watershed Canals & Streams: Water Years 1986-1995 (continued):

Map ID†	Monitoring Site/ Constituent	Median Constituent Concentration for a Given Water Year and Type									
		1986 Wet	1987 Critical	1988 Critical	1989 Critical	1990 Critical	1991 Critical	1992 Critical	1993 Wet	1994 Critical	1995 Wet
T-2	CCID Main @ Almond Dr.*										
	EC (umhos/cm):	550	550	—	—	—	—	—	—	—	—
	Boron (mg/L):	0.36	0.28	—	—	—	—	—	—	—	—
	Selenium (ug/L):	1	1.8	—	—	—	—	—	—	—	—
T-3	CCID Main @ Gun Club Rd*										
	EC (umhos/cm):	510	450	—	—	—	—	—	—	—	—
	Boron (mg/L):	0.36	0.26	—	—	—	—	—	—	—	—
	Selenium (ug/L):	1	1.4	—	—	—	—	—	—	—	—
T-4	Santa Fe Canal @ HWY 152*										
	EC (umhos/cm):	2200	2250	—	—	—	—	—	—	—	—
	Boron (mg/L):	3.4	4.3	—	—	—	—	—	—	—	—
	Selenium (ug/L):	27	36	—	—	—	—	—	—	—	—
T-5	Santa Fe Canal @ Henry Miller Road*										
	EC (umhos/cm):	2400	2800	—	—	—	—	—	1208	900	712
	Boron (mg/L):	3.3	3.8	—	—	—	—	—	1.2	0.63	0.35
	Selenium (ug/L):	25	30	—	—	—	—	—	5.3	1.8	1.7
T-6	Santa Fe Canal @ Gun Club Road*										
	EC (umhos/cm):	2150	1800	—	—	—	—	—	—	—	—
	Boron (mg/L):	2.7	1.2	—	—	—	—	—	—	—	—
	Selenium (ug/L):	9.9	1.2	—	—	—	—	—	—	—	—
T-7	San Luis Canal @ Hwy 152										
	EC (umhos/cm):	1200	2630	2550	1045	1400	1625	1030	878	935	809
	Boron (mg/L):	1.4	3.4	3.6	0.76	1.7	1.6	0.60	0.53	0.62	0.35
	Selenium (ug/L):	2	4	3.9	2.5	2.5	2.6	1.7	2.1	1.7	1.8
T-7A	San Luis Canal @ Henry Miller Road										
	EC (umhos/cm):	—	—	—	—	—	—	—	1730	980	728
	Boron (mg/L):	—	—	—	—	—	—	—	2.2	0.8	0.4
	Selenium (ug/L):	—	—	—	—	—	—	—	12	2.5	2.2
T-8	Los Banos Creek @ Gun Club Road*										
	EC (umhos/cm):	1250	1750	—	—	—	—	—	—	—	—
	Boron (mg/L):	1.3	0.67	—	—	—	—	—	—	—	—
	Selenium (ug/L):	1	0.9	—	—	—	—	—	—	—	—
T-9	Eagle Ditch @ Gun Club Rd.*										
	EC (umhos/cm):	1900	1200	—	—	—	—	—	—	—	—
	Boron (mg/L):	1.7	0.73	—	—	—	—	—	—	—	—
	Selenium (ug/L):	1.9	1.1	—	—	—	—	—	—	—	—
T-10	Mud Slough (north) @ Gun Club Road*										
	EC (umhos/cm):	2950	3000	—	—	—	—	—	—	—	—
	Boron (mg/L):	3.3	2.5	—	—	—	—	—	—	—	—
	Selenium (ug/L):	2	1.6	—	—	—	—	—	—	—	—
T-11	Freemont Canal @ Gun Club Road*										
	EC (umhos/cm):	2700	2700	—	—	—	—	—	—	—	—
	Boron (mg/L):	3.8	1.5	—	—	—	—	—	—	—	—
	Selenium (ug/L):	20	6.9	—	—	—	—	—	—	—	—
T-12	Gustine STP*										
	EC (umhos/cm):	2900	2600	—	—	—	—	—	—	—	—
	Boron (mg/L):	1.3	0.69	—	—	—	—	—	—	—	—
	Selenium (ug/L):	1	1.4	—	—	—	—	—	—	—	—
T-13	Porter Blake Bypass										
	EC (umhos/cm):	—	—	—	—	—	—	—	3360	3160	3040
	Boron (mg/L):	—	—	—	—	—	—	—	5.2	4.9	4.0
	Selenium (ug/L):	—	—	—	—	—	—	—	46	44	40

† Refers to Figure 1A in Appendix

Table 8. Median Constituent Concentrations for Grassland Watershed Canals & Streams: Water Years 1986-1995 (continued):

Map ID†	Monitoring Site/ Constituent	1986 Wet	1987 Critical	1988 Critical	1989 Critical	1990 Critical	1991 Critical	1992 Critical	1993 Wet	1994 Critical	1995 Wet
		Median Constituent Concentration for a Given Water Year and Type									
T-14	San Luis Spillway Ditch @ Santa Fe Grade										
	EC (umhos/cm):	—	—	—	—	—	—	—	778	820	907
	Boron (mg/L):	—	—	—	—	—	—	—	0.37	0.52	0.60
	Selenium (ug/L):	—	—	—	—	—	—	—	0.3	0.6	0.6
O-1	Mud Slough @ NGC										
	EC (umhos/cm):	1800	2600	2480	2310	2480	3540	3130	1980	1605	1550
	Boron (mg/L):	2.0	2.4	2.2	1.7	2.1	3.2	2.6	1.5	1.2	1.1
	Selenium (ug/L):	4	5.1	4.7	2.1	4.3	3.9	2.3	3	1.1	1
O-2	Mud Slough (north) @ HWY 140										
	EC (umhos/cm):	2300	2600	2820	3000	3060	—	—	—	—	—
	Boron (mg/L):	3.0	3.0	2.7	2.4	3.4	—	—	—	—	—
	Selenium (ug/L):	8.5	17	9.3	2.1	5.2	—	—	—	—	—
O-2A	Mud Slough (north) @ SLD										
	EC (umhos/cm):	2300	2600	2820	3000	3060	4030	3130	2495	2560	1570
	Boron (mg/L):	3.0	3.0	2.7	2.4	3.4	4.4	2.5	1.9	1.9	1.1
	Selenium (ug/L):	8.5	17	9.3	2.1	5.2	2.4	1.5	2	1	1
O-3	Los Banos Creek @ HWY 140										
	EC (umhos/cm):	2200	1855	1690	1630	1870	2745	1500	1478	1530	1000
	Boron (mg/L):	2.3	1.6	1.2	1.0	1.2	1.6	1.4	1.3	0.91	0.57
	Selenium (ug/L):	1	1.4	1.1	0.9	0.8	1	1.1	1	0.6	0.6
O-4	Salt Slough @ Lander										
	EC (umhos/cm):	1610	1720	1940	2040	2340	2460	2420	2270	2510	2070
	Boron (mg/L):	1.3	1.7	1.9	1.9	2.3	2.0	2.1	2.5	2.5	2.2
	Selenium (ug/L):	7.4	12	13	15	15	15	13	18	20	17
O-5	Salt Slough @ Wolfsen Road (San Luis Ranch)										
	EC (umhos/cm):	1300	1900	2200	—	—	—	—	—	—	—
	Boron (mg/L):	1.3	2.0	2.2	—	—	—	—	—	—	—
	Selenium (ug/L):	7.9	15	14	—	—	—	—	—	—	—
O-6	City Ditch-(San Luis Wasteway to Mud Slough)										
	EC (umhos/cm):	2600	3110	3280	—	—	3550	3750	—	—	—
	Boron (mg/L):	4.1	3.8	4.4	—	—	5.1	5.3	—	—	—
	Selenium (ug/L):	27	41	39	—	—	41	39	—	—	—
O-7	San Luis Drain @ Hwy 152										
	EC (umhos/cm):	—	—	—	—	—	—	—	—	—	7780
	Boron (mg/L):	—	—	—	—	—	—	—	—	—	15
	Selenium (ug/L):	—	—	—	—	—	—	—	—	—	3.7
O-8	Mud Slough (north) upstream of San Luis Drain										
	EC (umhos/cm):	—	—	—	—	—	—	—	1500	2000	1580
	Boron (mg/L):	—	—	—	—	—	—	—	1.2	1.6	1.1
	Selenium (ug/L):	—	—	—	—	—	—	—	2.7	1.1	0.6

† Refers to Figure 1A in Appendix

Table 9. Median Constituent Concentrations in Waterways Sampled Throughout the Grassland Watershed Between May 1985 and September 1995

Type	Station	EC (umhos/cm)	B mg/L	Se ug/L
I-1	Main (Firebaugh) Drain @ Russell Avenue	3340	4.5	52
I-2	Panoche Drain @ O'Banion Guage Station	4673	7.6	73
I-3	Agatha Inlet (Mercy Springs) Drain	3940	7.2	6.3
I-4	Agatha Canal @ Mallard Road	3650	6.0	39
I-5	Helm Canal	2600	4.3	20
I-6	Hamburg Drain	5080	5.5	83
I-7	Camp 13 Slough @ Guage Station	3870	5.4	53
I-8	Charleston Drain @ CCID Main Canal	4410	4.1	68
I-9	Almond Drain	1520	1.3	3.0
I-10	Rice Drain @ Mallard Road	2640	4.9	2.9
I-11	Boundary Drain @ DFG Pump	1375	0.5	1.0
I-12	Salt Slough @ Hereford	1040	0.3	0.9
I-13	Garzas Creek @ Hunt Road	800	0.6	1.9
T-1	CCID Main Canal @ Russell Ave.	700	0.3	1.6
T-2	CCID Main @ Almond Drive	585	0.4	1.1
T-3	CCID Main @ Gun Club Road	510	0.3	1.4
T-4	Santa Fe Canal @ Highway 152	2233	3.3	23
T-5	Santa Fe Canal @ Henry Miller Rd.	1070	1.0	3.0
T-6	Santa Fe Canal @ Gun Club Road	1733	2.5	6.0
T-7	San Luis Canal @ Henry Miller Rd.	2000	2.3	12
T-7A	San Luis Canal @ Highway 152	1460	1.5	2.6
T-8	Los Banos Creek @ Gun Club Road	1300	1.2	1.0
T-9	Eagle Ditch @ Gun Club Road	1530	1.4	2.2
T-10	Mud Slough (north) @ Gun Club Road	2900	3.3	2.0
T-11	Fremont Canal @ Gun Club Road	2575	3.4	16
T-12	Gustine Sewage Treatment Plant Ditch	2800	1.1	1.2
T-13	Porter-Blake Bypass	3130	4.7	40
T-14	San Luis Spillway Ditch @ Santa Fe Grade	820	0.5	0.6
O-1	Mud Slough (north) @ Newman Gun Club	3090	2.6	2.8
O-2	Mud Slough (north) @ Highway 140	2800	2.8	5.4
O-2A	Mud Slough (north) downstream of San Luis Drain	2870	2.3	1.5
O-3	Los Banos Creek	1680	1.2	1.0
O-4	Salt Slough @ Lander	2150	2.1	15
O-5	Salt Slough @ Wolfson Road	1700	1.6	6.0
O-6	City Ditch	3200	4.5	33
O-7	San Luis Drain @ Highway 152	7840	14	2.0
O-8	Mud Slough (north) upstream of San Luis Drain	1590	1.1	0.8

I = Inflow
T = Internal flow
O = Outflow

Electrical conductivity, boron, and selenium monthly means were calculated for the 10-year study for each WY month in order to get a perspective of seasonal water quality over a period of time. Figures 9, 10 and 11 show the 10-year monthly means for EC, boron, and selenium, respectively. The boron and selenium water quality objectives are shown in the figures as a point of reference. The monthly means were calculated by averaging mean monthly concentration of the constituent in question over the 10-water year period. An example would be as follows: the mean monthly value for May over the 10-water year period would be (May-86+ May-87...+May-95) divided by the total number of months of sample data. For some WYs, there are months where no data was collected, and the derived statistics reflect these data gaps.

Seasonally, peak EC, boron and selenium concentrations occur during January and February in Salt Slough. Conversely, in Mud Slough, peak EC and boron concentrations tend to occur in May, June and July with selenium peaking during July and August. These trends suggest different constituent sources in conjunction with varying dilution flows. The early seasonal elevated levels in Salt Slough may be associated with pre-irrigation practices and increased subsurface drainage. Later peaks of EC and boron in Mud Slough may be associated with tail water and late wetland drainage.

Lower San Joaquin River: WYs 86-95

Annual median electrical conductivity, boron, and selenium concentrations for the 10-year study at Hills Ferry, Crows Landing, and Vernalis river crossings are shown in Figures 12,13, and 14, respectively. Figure 15 shows the annual flows at the three river sites for comparison. Tables 10 and 11 list the minimum, median, and maximum EC, boron, and selenium concentrations for each San Joaquin River monitoring site over the 10-year study.

The San Joaquin River at the Hills Ferry Road monitoring site is dominated by flows from Mud Slough (north) and Salt Slough and reflects the quality of water flowing through those channels. Between Hills Ferry Road and the Crows Landing Bridge, the river receives inflows from a number of drains and operational spills as well as the Merced River (Table 1). Although these inflows contain agricultural discharges, when combined with Merced River inflows, the overall boron and selenium concentrations are lower than those found in Mud Slough (north) and Salt Slough as reflected in the decreasing river concentration. Downstream of the Crows Landing Bridge site, the San Joaquin River receives inflow from two additional east side tributaries: the Tuolumne and Stanislaus Rivers. Salt, boron and selenium concentrations are very low in these tributaries and these inflows improve the water quality in the San Joaquin River accordingly.

Annual median selenium concentration has fluctuated at both the Hills Ferry Road and Crows Landing Bridge sites since WY 86. This fluctuation is due to upstream dilution flows. During higher than normal precipitation years, east side tributary flows dominate characteristics at the site. During normal to below normal water years, Mud Slough (north) and Salt Slough dominate the characteristics. The Hills Ferry Road site is just downstream of the confluence with Mud Slough (north) and Salt Slough but upstream of the Merced River inflow. Mud Slough (north), as with Salt Slough, can carry agricultural return flows, storm water, and wetland releases. Drainage flows can readily be switched between the two sloughs through a series of diversion structures so that either slough is able to carry runoff from the other's watershed.

Figure 9. Monthly Mean Electrical Conductivity at Mud Slough (north) and Salt Slough: WYs 86-95

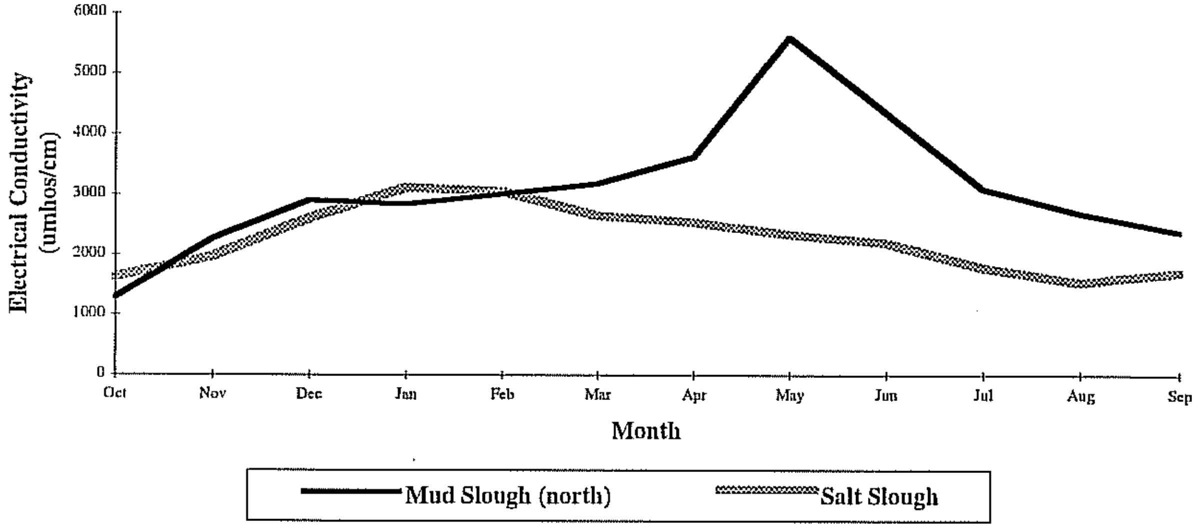


Figure 10. Monthly Mean Boron Concentrations at Mud Slough (north) and Salt Slough: WYs 86-95

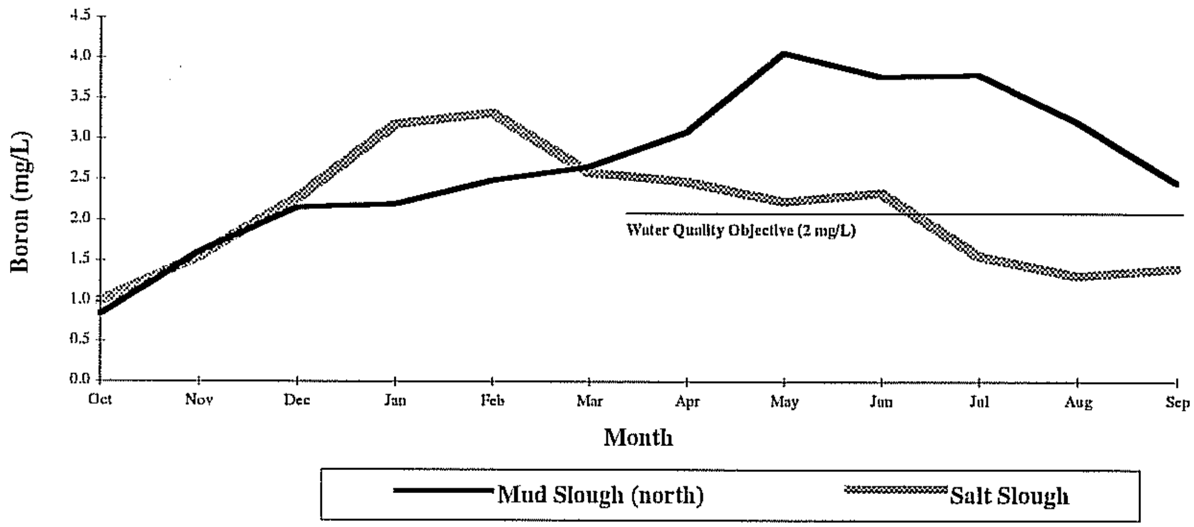


Figure 11. Monthly Mean Selenium Concentrations at Mud Slough (north) and Salt Slough: WYs 86-95

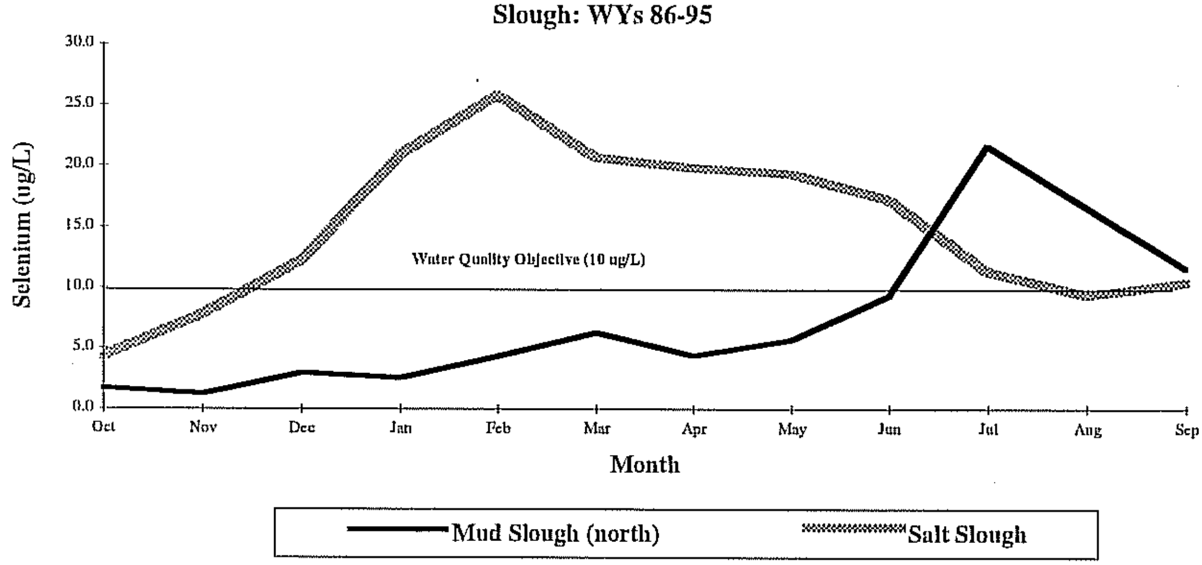


Figure 12. Annual Median Electrical Conductivity Values for Crows Landing Bridge, Hills Ferry Road, and Airport Way Monitoring Sites: WYs 86-95

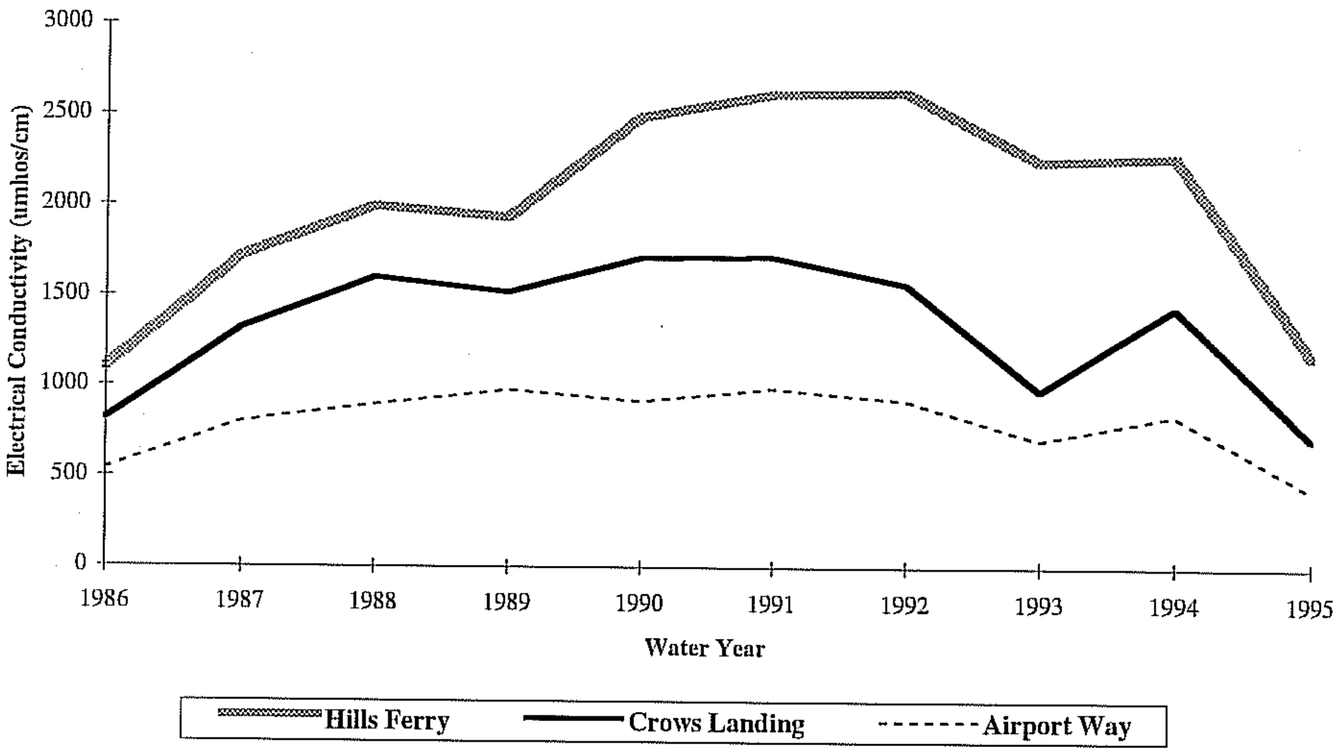


Figure 13. Annual Median Boron Values for Crows Landing Bridge, Hills Ferry Road, and Airport Way Monitoring Sites: WYs 86-95

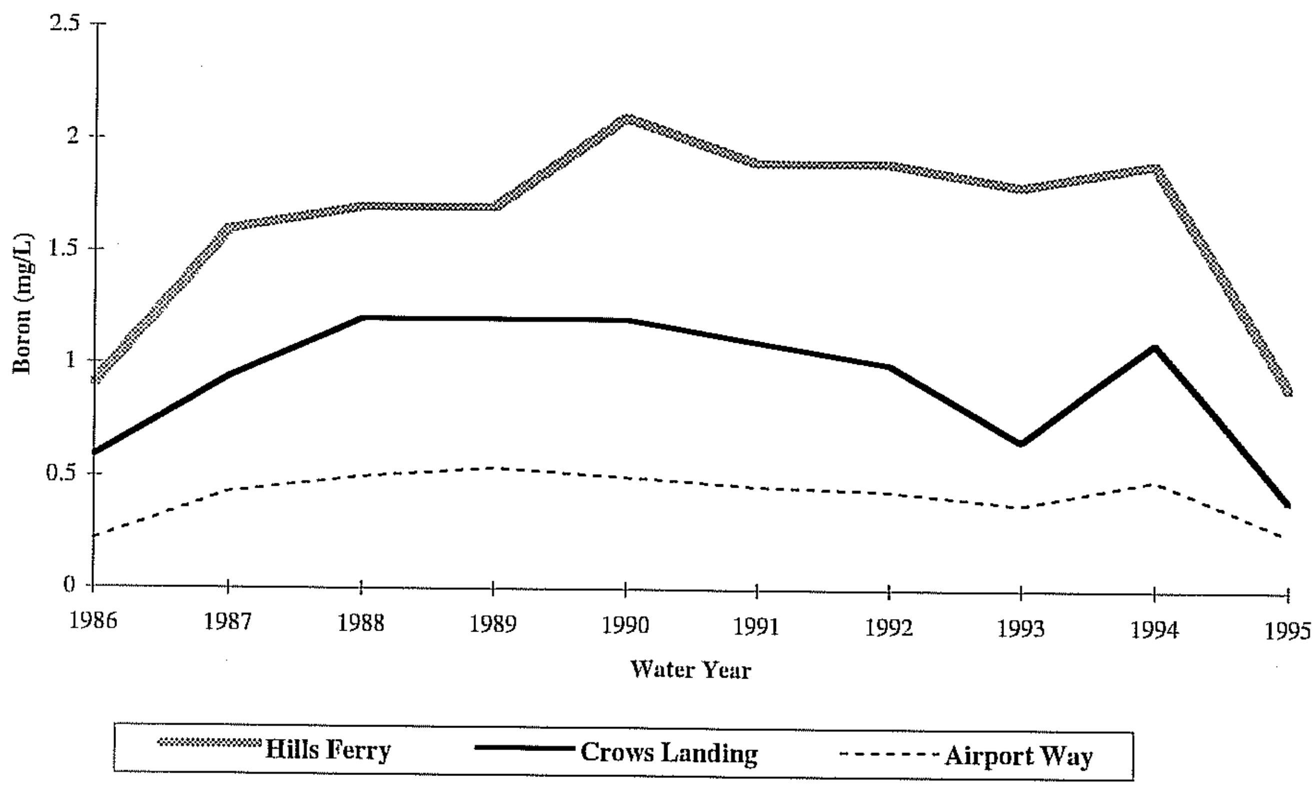


Figure 14. Annual Median Selenium Values for Crows Landing Bridge, Hills Ferry Road, and Airport Way Monitoring Sites: WYs 86-95

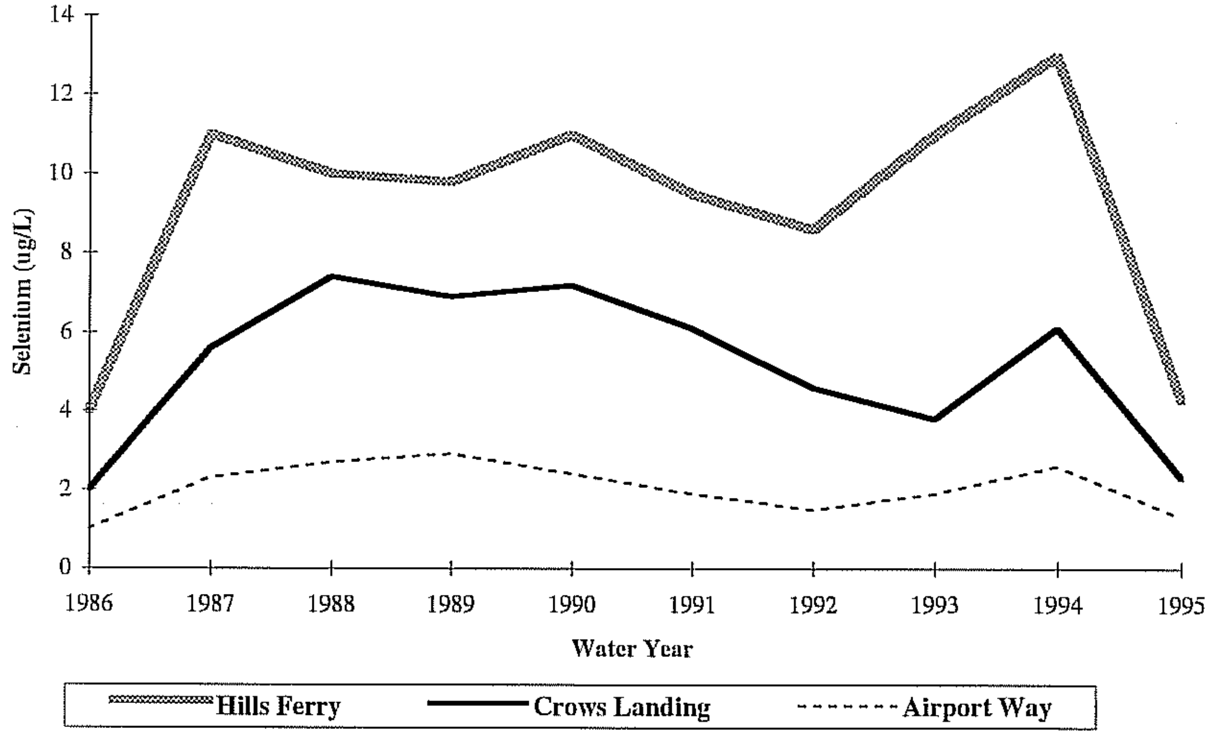


Figure 15. Annual San Joaquin River Flows at Hills Ferry, Crows Landing, and Airport Way: WYs 86-95

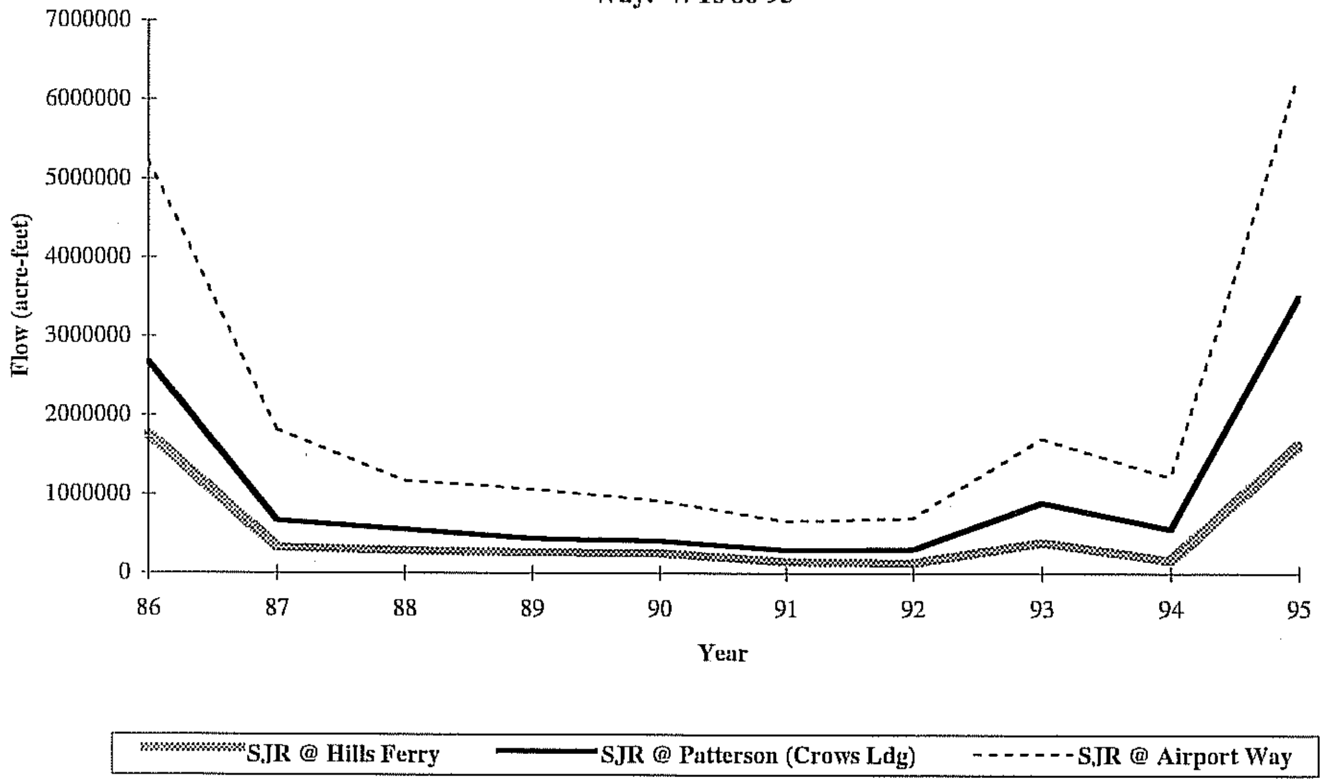


Table 10. Range of Electrical Conductivity and Boron Concentration by Water Year (WY) for Monitoring Sites Along the Lower San Joaquin River: WYs 86-95. (Data from James et al., 1988; Westcot et al., 1989, 1990, 1991 and 1992; Karkoski and Tucker 1993; Chilcott et al., 1995; and Steensen et al., 1997.)

Water Year/Type		AIRPORT WAY	MAZE BOULEVARD	GRAYSON ROAD	LAS PALMAS AVENUE	CROWS LANDING	HILLS FERRY	FREMONT FORD	LANDER AVENUE
WY 1986 WET									
EC (µmhos/cm)	Minimum:	180	200	280	240	270	410	94	73
	Median:	540	700	960	870	815	1100	905	400
	Maximum:	980	1100	1700	1800	1700	2600	2300	930
	# Samples:	(18)	(17)	(15)	(18)	(18)	(18)	(18)	(18)
B (mg/L)	Minimum:	0.10	0.13	0.17	0.11	0.14	0.29	0.09	<0.01
	Median:	0.22	0.39	0.57	0.56	0.59	0.91	0.65	0.10
	Maximum:	0.7	0.70	1.2	1.7	1.2	2.2	1.8	0.61
	# Samples:	(17)	(17)	(15)	(18)	(18)	(18)	(18)	(18)
WY 1987 CRITICAL									
EC (µmhos/cm)	Minimum:	340	490	1200	1200	1200	1600	1330	650
	Median:	804	1100	1300	1360	1320	1720	1730	1200
	Maximum:	930	1420	1890	1960	1990	2600	2880	1650
	# Samples:	(13)	(9)	(9)	(9)	(13)	(10)	(12)	(13)
B (mg/L)	Minimum:	0.18	0.30	0.59	0.70	0.67	0.53	0.81	0.10
	Median:	0.43	0.64	0.88	0.95	0.94	1.6	1.6	0.21
	Maximum:	0.62	1.1	1.6	1.8	1.9	3.0	3.2	0.35
	# Samples:	(15)	(11)	(11)	(11)	(15)	(13)	(14)	(15)
WY 1988 CRITICAL									
EC (µmhos/cm)	Minimum:	650	1010	1300	750	1180	1380	1260	320
	Median:	900	1400	1580	1600	1600	1990	1950	1550
	Maximum:	1450	1600	1950	2150	2150	3100	2950	2100
	# Samples:	(43)	(13)	(12)	(14)	(43)	(41)	(42)	(40)
B (mg/L)	Minimum:	0.28	0.50	0.66	0.48	0.46	0.57	0.41	0.03
	Median:	0.50	0.90	1.0	1.2	1.2	1.7	1.8	0.30
	Maximum:	0.95	1.1	1.5	3	2	3.1	2.8	0.47
	# Samples:	(43)	(13)	(12)	(14)	(43)	(41)	(42)	(40)
WY 1989 CRITICAL									
EC (µmhos/cm)	Minimum:	720	880	1160	1220	1000	1360	1300	380
	Median:	980	1290	1480	1490	1520	1930	2010	1500
	Maximum:	1510	1740	2100	2220	2210	3350	3300	1990
	# Samples:	(46)	(14)	(13)	(13)	(47)	(46)	(47)	(47)
B (mg/L)	Minimum:	0.37	0.60	0.64	0.76	0.68	0.69	0.67	0.06
	Median:	0.54	0.80	0.9	1.0	1.2	1.7	1.8	0.32
	Maximum:	1.0	1.2	1.6	1.8	1.9	3.0	3.3	0.54
	# Samples:	(45)	(14)	(13)	(13)	(46)	(46)	(46)	(46)
WY 1990 CRITICAL									
EC (µmhos/cm)	Minimum:	600	930	1250	1060	1180	1120	1180	440
	Median:	920	1340	1430	1530	1710	2490	2400	1500
	Maximum:	1380	1640	1900	2160	2030	4120	3070	2940
	# Samples:	(49)	(35)	(12)	(12)	(49)	(46)	(49)	(48)
B (mg/L)	Minimum:	0.31	0.55	0.66	0.67	0.67	0.88	0.82	0.09
	Median:	0.50	0.79	0.91	1.1	1.2	2.1	2.0	0.33
	Maximum:	1.1	1.2	1.2	1.5	1.7	3.2	3.3	0.69
	# Samples:	(49)	(35)	(12)	(12)	(49)	(48)	(49)	(49)
WY 1991 CRITICAL									
EC (µmhos/cm)	Minimum:	410	530	600	560	560	750	600	150
	Median:	990	1280	1670	1740	1720	2620	2620	2240
	Maximum:	1680	1750	2310	2450	2490	4360	4290	3420
	# Samples:	(54)	(54)	(38)	(38)	(53)	(53)	(52)	(52)
B (mg/L)	Minimum:	0.20	0.28	0.31	0.28	0.30	0.46	0.37	0.08
	Median:	0.46	0.64	0.92	1.0	1.1	1.9	2.0	0.43
	Maximum:	1.2	1.3	1.7	1.9	2.1	3.4	4.4	0.75
	# Samples:	(54)	(54)	(38)	(38)	(53)	(53)	(52)	(52)
WY 1992 CRITICAL									
EC (µmhos/cm)	Minimum:	389	410	895	880	670	880	820	100
	Median:	925	1260	1530	1570	1570	2630	2670	2200
	Maximum:	1450	1540	1950	2060	2180	3620	3800	3990
	# Samples:	(58)	(58)	(53)	(54)	(58)	(58)	(58)	(53)
B (mg/L)	Minimum:	0.16	0.20	0.25	0.24	0.23	0.34	0.28	0.038
	Median:	0.44	0.61	0.74	0.86	1.0	1.9	1.9	0.46
	Maximum:	0.93	1.1	1.4	1.5	1.8	3.2	4.9	0.98
	# Samples:	(58)	(58)	(53)	(53)	(57)	(56)	(57)	(52)
WY1993 ABOVE NORMAL									
EC (µmhos/cm)	Minimum:	360	380	690	410	330	430	210	130
	Median:	708	881	1400	1090	980	2250	2120	1230
	Maximum:	1420	1620	1580	2000	1940	3650	3710	4060
	# Samples:	(50)	(50)	(6)	(50)	(50)	(50)	(50)	(50)
B (mg/L)	Minimum:	0.01	0.17	0.23	0.21	0.17	0.27	0.1	0.04
	Median:	0.38	0.48	0.50	0.67	0.66	1.8	1.7	0.28
	Maximum:	0.83	0.92	1.3	1.3	2.1	3.0	3.5	1.1
	# Samples:	(50)	(50)	(6)	(50)	(50)	(50)	(50)	(50)
WY1994 CRITICAL									
EC (µmhos/cm)	Minimum:	217	211	—	249	209	1030	1110	204
	Median:	845	1040	—	1450	1440	2280	2430	1190
	Maximum:	1270	1510	—	2030	2040	3670	3590	1950
	# Samples:	(50)	[51]	—	[51]	[52]	[52]	[52]	[51]
B (mg/L)	Minimum:	0.07	0.08	—	0.11	0.11	0.61	0.67	<0.05
	Median:	0.49	0.64	—	0.97	1.1	1.9	2.1	0.29
	Maximum:	0.95	1.0	—	1.8	1.9	5.0	4.0	0.65
	# Samples:	[49]	[51]	—	[51]	[52]	[52]	[52]	[52]
WY1995 WET									
EC (µmhos/cm)	Minimum:	123	125	—	146	143	258	64	46
	Median:	429	442	—	696	716	1180	1190	238
	Maximum:	1020	1220	—	2120	2060	3050	3030	2450
	# Samples:	[46]	[43]	—	[45]	[48]	[49]	[45]	[45]
B (mg/L)	Minimum:	0.06	<0.05	—	0.08	0.05	0.17	<0.05	<0.05
	Median:	0.25	0.29	—	0.43	0.40	0.90	0.87	0.08
	Maximum:	0.56	4.5	—	1.8	1.7	2.8	3.0	0.6
	# Samples:	[48]	[45]	—	[46]	[50]	[48]	[46]	[16]

Table 11. Range of Selenium Concentration by Water Year (WY) for Monitoring Sites Along the Lower San Joaquin River (Data from James et al., 1988; Westcot et al., 1989, 1990, 1991 and 1992; Karkoski and Tucker, 1993; Chilcott et al., 1995; and Steensen et al., 1996.)

WATER YEAR/TYPE		AIRPORT WAY	MAZE BLVD	GRAYSON ROAD	LAS PALMAS AVENUE	CROWS LANDING	HILLS FERRY	FREMONT FORD	LANDER AVENUE
WY 1986	WET								
	Minimum	0.6 (<1)	0.8 (<1)	0.9 (<1)	<1	<1	<1	<1	0.2 (<1)
Se	Median	1	1.5	2.2	2	2	4	1.7	0.3
(µg/L)	Maximum	4	2.4	4	5	4	8	9	5
	# Samples	(19)	(19)	(16)	(18)	(19)	(19)	(19)	(19)
WY 1987	CRITICAL								
	Minimum	0.9	1.4	3.4	3.4	3.6	6.6	4.3	0.4
Se	Median	2.3	3.3	4.6	4.8	5.6	11	10	0.7
(µg/L)	Maximum	3.2	5.8	9.3	10	12	21	26	1.8
	# Samples	(15)	(11)	(11)	(11)	(15)	(15)	(14)	(15)
WY 1988	CRITICAL								
	Minimum	0.8	1.9	2.4	2.0	0.8	1.0	1.3	0.2
Se	Median	2.7	5.1	5.8	6.2	7.4	10	12	0.7
(µg/L)	Maximum	6.5	6.5	8.5	9.1	12	20	23	1.4
	# Samples	(41)	(13)	(12)	(14)	(42)	(41)	(40)	(38)
WY 1989	CRITICAL								
	Minimum	1.4	3.2	3.5	3.0	3.4	2.8	3.4	0.3
Se	Median	2.9	4.4	5.8	6.0	6.9	9.8	12	0.5
(µg/L)	Maximum	6.8	8.0	12	14	17	23	32	1.3
	# Samples	(46)	(14)	(13)	(13)	(47)	(46)	(47)	(46)
WY 1990	CRITICAL								
	Minimum	0.8	1.7	2.9	1.7	1.6	2.7	4.4	<0.2
Se	Median	2.4	4.0	5.0	4.6	7.2	11	14	0.4
(µg/L)	Maximum	9.6	9.8	10	10	13	26	33	1.7
	# Samples	(49)	(35)	(12)	(12)	(49)	(49)	(49)	(49)
WY 1991	CRITICAL								
	Minimum	0.5	0.8	1.0	0.6	0.7	1.0	0.9	0.2
Se	Median	1.9	2.7	4.3	4.9	6.1	9.5	13	0.4
(µg/L)	Maximum	4.8	5.6	7.3	8.3	11	24	30	0.8
	# Samples	(54)	(54)	(38)	(38)	(53)	(53)	(52)	(52)
WY 1992	CRITICAL								
	Minimum	0.4	0.4	0.6	0.5	0.5	1.0	0.8	0.1
Se	Median	1.5	2.1	3.3	3.2	4.6	8.6	11	0.3
(µg/L)	Maximum	4.4	5.4	7.2	8.2	11	19	25	0.6
	# Samples	(57)	(57)	(53)	(54)	(57)	(58)	(58)	(48)
WY 1993	ABOVE NORMAL								
	Minimum	0.20	0.50	0.30	0.20	0.20	0.60	0.60	0.10
Se	Median	1.9	2.3	1	3.5	3.8	11	13	0.50
(µg/L)	Maximum	6.1	4.9	1.3	6.7	8.5	23	29	1.3
	# Samples	(50)	(50)	(6)	(50)	(50)	(50)	(50)	(50)
WY 1994	CRITICAL								
	Minimum	0.4	0.2		0.2	0.3	1.2	1.2	<0.2
Se	Median	2.6	3.6		5.1	6.1	13	19	0.5
(µg/L)	Maximum	6.3	7.0		14	13	28	35	1.8
	# Samples	(50)	(51)		(51)	(52)	(52)	(52)	(52)
WY 1995	WET								
	Minimum	0.40	<.4		<.4	0.50	0.70	<.4	<.4
Se	Median	1.3	1.2		2.0	2.3	4.3	5.0	<.4
(µg/L)	Maximum	3.5	3.9		23	12	20	25	0.8
	# Samples	[48]	[44]		[47]	[51]	[48]	[47]	[16]

Selenium concentration trends similar to the Hills Ferry Road site were seen at the Crows Landing Bridge site. Crows Landing is the first site monitored downstream of the Merced River inflow. The effect of inflow from this east side tributary on the water quality of the San Joaquin River can be seen by the sharp decline in median constituent concentrations (Figure 16). High precipitation that fell during WY 86, 93 and 95 likely increased dilution flows which is demonstrated by further declines in concentration, indicating the strong influence an above normal precipitation year can have on the water quality of the San Joaquin River.

A seasonal study was conducted, similar to the one discussed earlier for Mud Slough (north) and Salt Slough using 10-water year monthly means of boron and selenium concentrations as well as EC, for the San Joaquin River sites at Hills Ferry Road, Crows Landing Bridge, and Airport Way (Figures 17 through 19). Figure 20 shows the variability in the monthly mean selenium concentrations at Crows Landing between October 1985 and September 1995. All three constituents show decreased concentrations with respect to site location downstream of a tributary inflow and the subsequent dilution that takes place. Data indicates that boron and EC concentrations tend to increase rapidly in the river during December at the Hills Ferry Road site. This increase likely reflects precipitation throughout the entire upper watershed. Selenium, while the concentrations increase in December, doesn't show the same pattern as EC and boron. Selenium concentration corresponds to agricultural irrigation events and the discharge of subsurface drain water from the Grassland Watershed. Peak subsurface drainage discharges occur during pre-irrigation (February and March) and remain relatively constant during the irrigation season (May through August).

Comparison to Water Quality Objectives

As previously discussed and presented in Table 7, the Central Valley Regional Board adopted selenium, boron and molybdenum Water Quality Objectives (WQOs) for the lower San Joaquin River from the Sack Dam to Vernalis in 1988 (Resolution #88-195). In December 1992, the USEPA promulgated a 5μg/L, 4-day average and 20 μg/L maximum selenium water quality criteria for the same reach of the San Joaquin River.

As specified in the San Joaquin River Basin Plan (December 1988), compliance monitoring for selenium and boron WQOs occurs on the San Joaquin River at the Crows Landing Bridge site. The Crows Landing Bridge site is downstream of the Merced River inflow and also receives water from agricultural return flows and ground water seepage. Boron and selenium WQOs adopted for the river at the Crows Landing Bridge site depended on the water-year type. Slightly relaxed objectives are implemented during critical water years reflecting the lack of good quality dilution flow from excess tailwater and/or natural flow from the east side tributaries.

The 1988 Basin Plan specified that electrical conductivity objectives would be established on the San Joaquin River near Vernalis. In May 1991, the State Water Resources Control Board adopted a 1,000μmhos/cm objective between September 1 and March 31 and a 700 μmhos/cm objective between April 1 and August 31.

These objectives were adopted as a 30-day running average. Although the salinity objectives did not apply until May 1991, Table 12 and Figure 21 indicate when the objectives would have been exceeded during the 10-year study period (WYs 86-95), based on monthly means and instantaneous grab sample concentrations, respectively. Based on monthly means, the salinity objectives were frequently exceeded during critical water years, primarily during pre-irrigation (December through February) and irrigation (April through August). During wet water years, the salinity objectives were rarely exceeded.

Figure 16. Selenium Concentrations at Selected Monitoring Sites on the Lower San Joaquin River: 24 June 1993

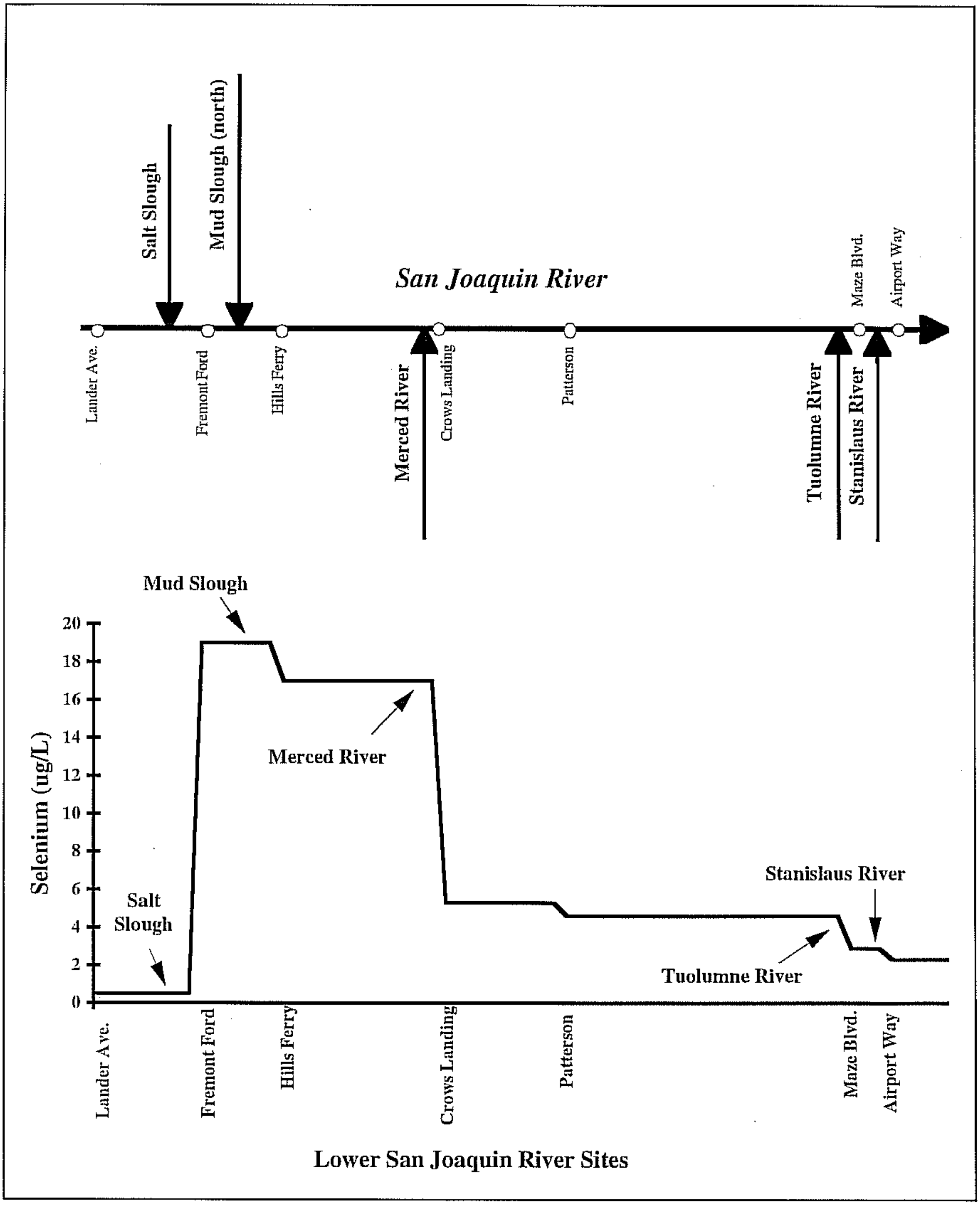


Figure 17. Monthly Mean Electrical Conductivity at Hills Ferry Road, Crows Landing Bridge, and Airport Way Monitoring Sites: WYs 86-95

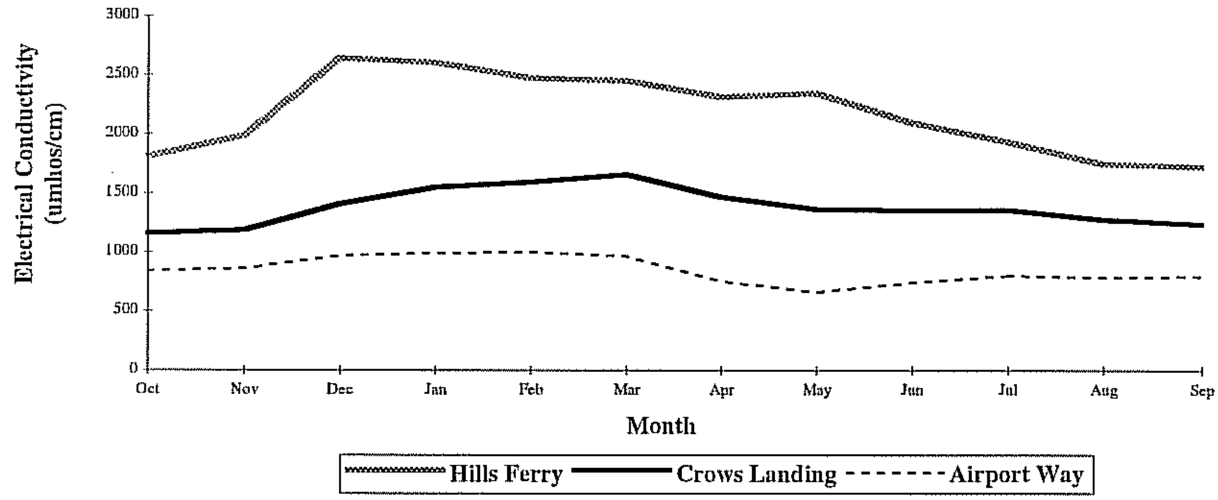


Figure 18. Monthly Mean Boron at Hills Ferry Road, Crows Landing Bridge, and Airport Way Monitoring Sites: WYs 85-95

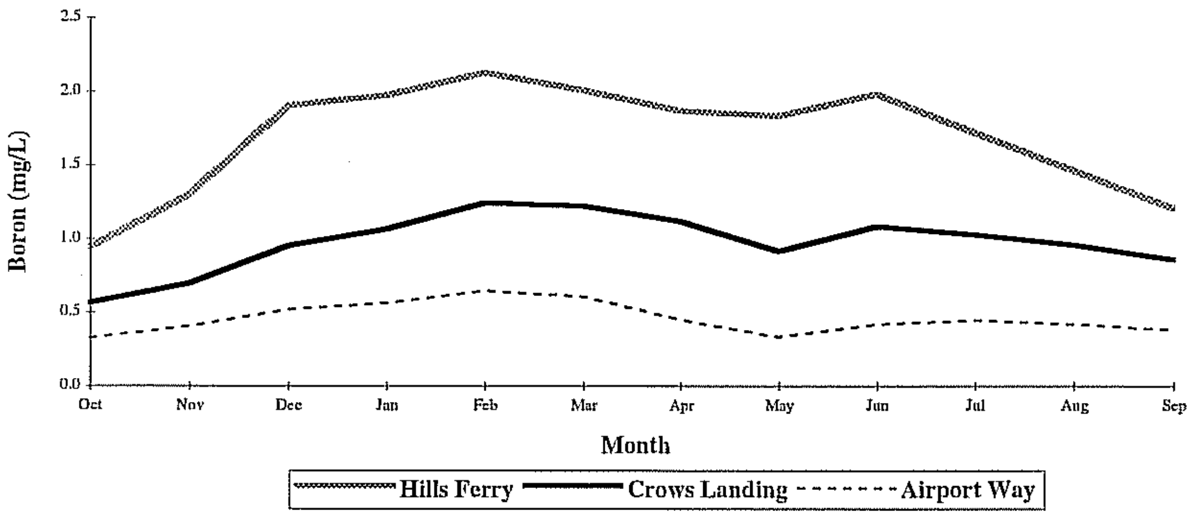
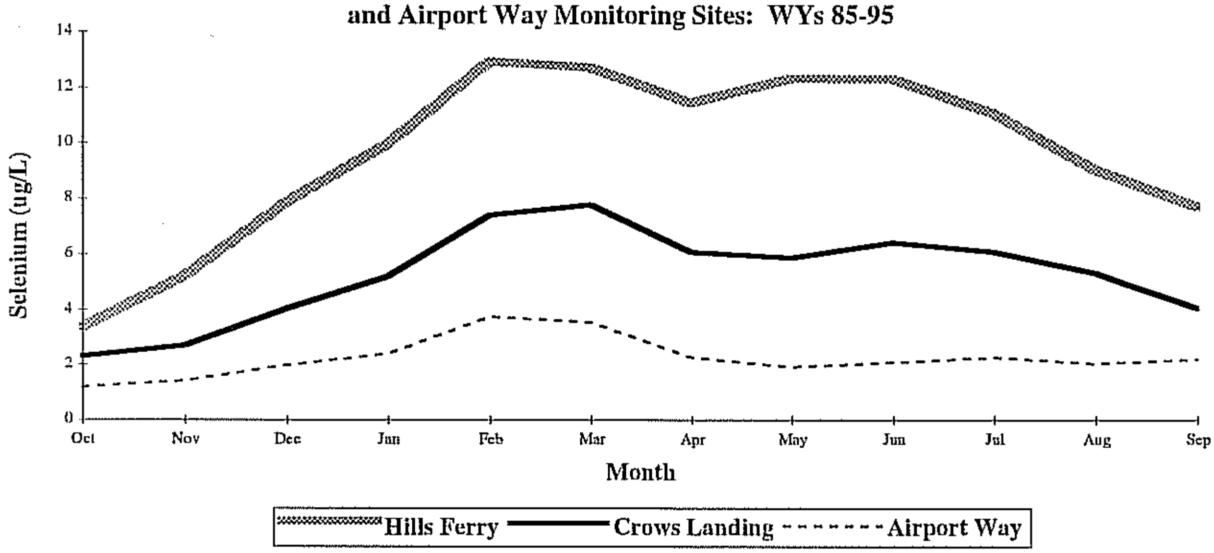
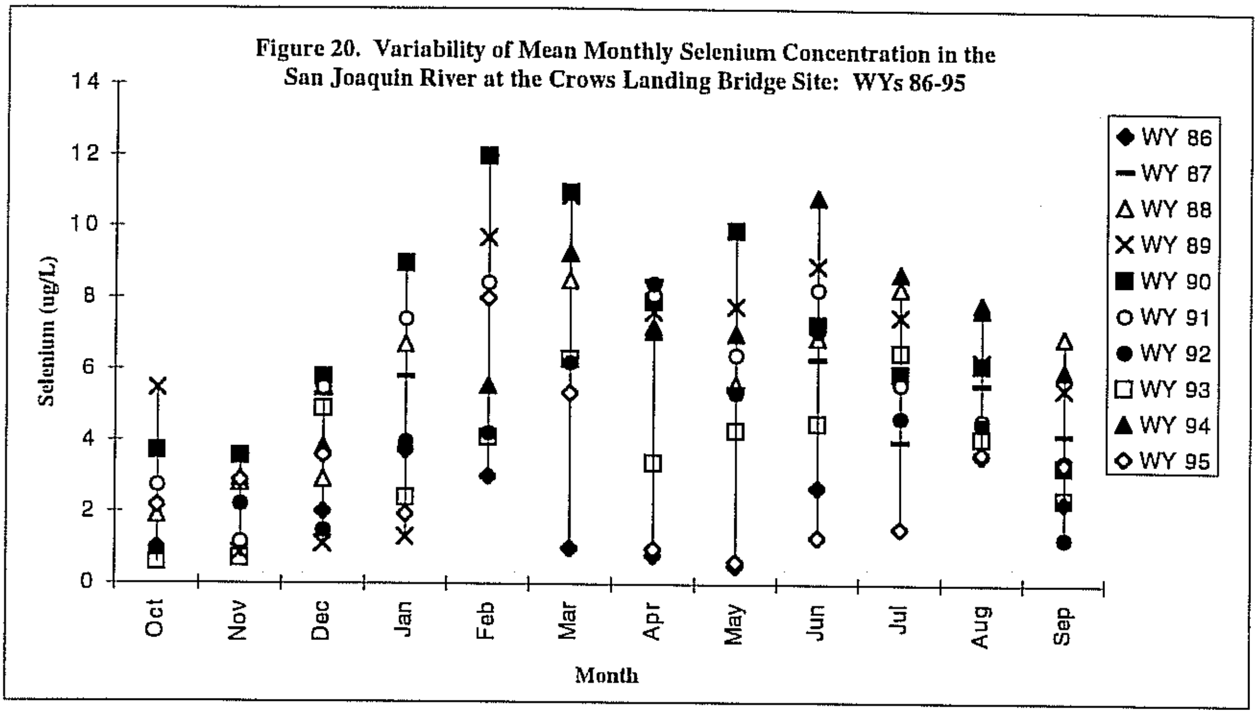


Figure 19. Monthly Mean Selenium at Hills Ferry Road, Crows Landing Bridge, and Airport Way Monitoring Sites: WYs 85-95





Monthly mean and maximum boron WQOs on the San Joaquin River from Sack Dam to the mouth of the Merced River are 2.0 mg/L and 5.8 mg/L, respectively (15 March-15 September). Boron concentrations in the San Joaquin River at the Hills Ferry Road site are used to determine compliance with this objective. Monthly mean WQOs for boron from the mouth of the Merced River to Vernalis are 0.8 mg/L (15 March-15 September) and 1.0 mg/L (16 September-14 March). Maximum boron WQOs are 2.0 mg/L (15 March-15 September) and 2.6 mg/L (16 September-14 March) for the same river segment.

Tables 13 and 14 show the mean monthly boron water quality objective exceedances in the San Joaquin River at the Hills Ferry Road and Crows Landing Bridge sites, respectively. At both locations, the boron objectives were primarily exceeded during critical water years. Upstream of the Merced River, at Hills Ferry, the exceedances are clustered during the early irrigation season. (April through June) and at the tail end of pre-irrigation and the main period of duck club releases (March). Downstream of the Merced River, at the Crows Landing Road Bridge site, the exceedances are more scattered but still fall primarily between February and June.

Since WY 86, time periods of selenium WQO exceedance at the Crows Landing Bridge site appear to be centered between February and April, as well as June and July (Table 15). These two time periods correspond to typical periods of pre-irrigation and the growing season, respectively.

Table 16 depicts the number of months that selenium would have exceeded the 5 μg/L selenium criteria promulgated by the USEPA had it been in effect during the critically dry water years of 1987 through 1992 and 1994.

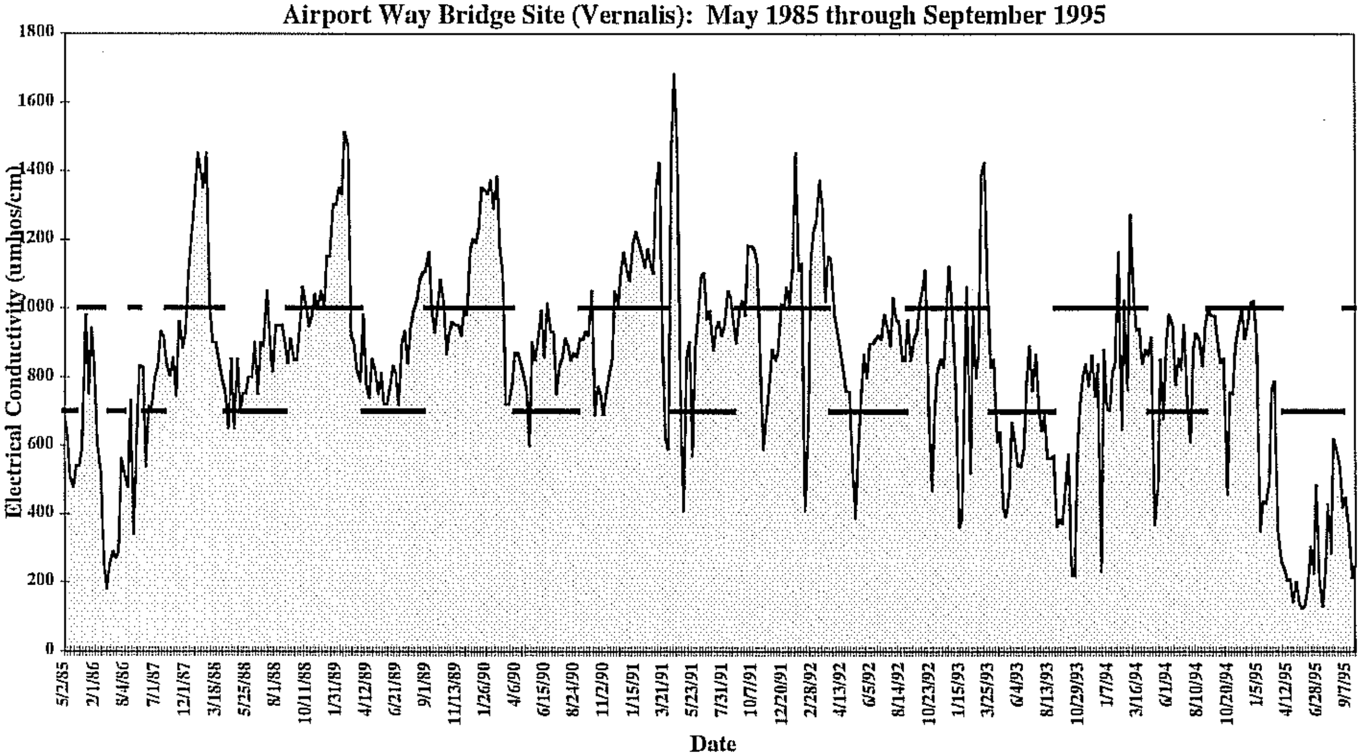
Table 12. Monthly Mean Salinity Water Quality Objective Exceedances in the San Joaquin River at the Airport Way Bridge Site (Vernalis): WYs 86-95

Water Year	Type	Monthly Mean Water Quality Objective Exceedances*											
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1986	wet												
1987	critical												
1988	critical												
1989	critical												
1990	critical												
1991	critical												
1992	critical												
1993	wet												
1994	critical												
1995	wet												
Water Quality Obj:		1000 umhos/cm						700 umhos/cm					1000*

* The 1000 umhos/cm objective applies from September through March.

= Exccedance based on monthly mean concentration rather than 30-day running average.

Figure 21. Electrical Conductivity in the San Joaquin River at the Airport Way Bridge Site (Vernalis): May 1985 through September 1995



Note: This is for illustration purposes only as the data presented is a comparison of the 30-day running average objective to an instantaneous grab sample .

Table 13. Mean Monthly Boron Water Quality Objective Exceedances in the San Joaquin River at the Hills Ferry Bridge Site: WYs 86-95.

Water Year	Type	Monthly Mean Water Quality Objective Exceedances*											
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1986	wet												
1987	critical												
1988	critical												
1989	critical												
1990	critical												
1991	critical												
1992	critical												
1993	wet												
1994	critical												
1995	wet												
Water Quality Obj:		—	—	—	—	—	2.0 mg/L						

* The 2.0 mg/L objective applies from 15 March through 15 September.

= Water quality objective exceedance.

Table 14. Mean Monthly Boron Water Quality Objective Exceedances in the San Joaquin River at the Crows Landing Bridge Site: WYs 86-95.

Water Year	Type	Monthly Mean Water Quality Objective Exceedances*											
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1986	wet												
1987	critical												
1988	critical												
1989	critical												
1990	critical												
1991	critical												
1992	critical												
1993	wet												
1994	critical												
1995	wet												
Wet year WQO:		1.0 mg/L					0.8 mg/L						
Critical year WQO:		1.3 mg/L											

* During non-critical water years, the 0.8 mg/L boron WQO applies from 15 March through 15 September

= Water quality objective exceedance.

Table 15. Mean Monthly Selenium Water Quality Objective Exceedances in the San Joaquin River at the Crows Landing Bridge Site: WYs 86-95

Water Year	Type	Se (ug/L) WQO†	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
			Monthly Mean Water Quality Objective Exceedances*											
1986*	wet	5												
1987*	critical	8												
1988**	critical	8												
1989**	critical	8												
1990**	critical	8												
1991**	critical	8												
1992**	critical	8												
1993**	wet	5												
1994**	critical	8												
1995**	wet	5												

* Samples were collected once a month
** Samples were collected weekly and the concentrations averaged
Exceedance of objective
† WQOs shown were adopted in 1988

Table 16. Projected Exceedences of the Selenium Water Quality Criteria Promulgated by the U.S. EPA in the San Joaquin River at the Crows Landing Bridge Site had the Criteria Been in Place During Water Years 1986 through 1995.

Water Year	Type	Se (ug/L) WQC†	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
			Monthly Mean Water Quality Objective Exceedances*											
1986*	wet	5												
1987*	critical	5												
1988**	critical	5												
1989**	critical	5												
1990**	critical	5												
1991**	critical	5												
1992**	critical	5												
1993**	wet	5												
1994**	critical	5												
1995**	wet	5												

* Samples were collected once a month
** Samples were collected weekly and the concentrations averaged
Exceedance of objective
† WQ criteria shown was promulgated by the U.S. EPA in 1992
Note: This table is for illustration purposes only as the U.S. EPA criteria was not promulgated until water year 1993 and this table compares a 4-day average criteria to an instantaneous grab sample obtained during this study period.

LOADS

Loads reported here are based on Regional Board water quality and discharge data from various sources (Table 17). Loads for the Drainage Problem Area (DPA) are calculated by summing loads from four drains and accounting for any recirculation. The four drains used to estimate the total DPA load are Firebaugh Main Drain (includes drainage from Broadview Water District, Central California Irrigation District, and Firebaugh Water District), Panoche Drain, Charleston Drain, and Hamburg Drain (Pacheco Water District). Loads recirculated with Central California Irrigation District (CCID) supply water are then subtracted from this amount. Loads for selenium and boron are given in pounds and salt, in tons. Flow weighted concentrations for salt and boron are given in units of mg/L and selenium, in μg/L Tables 18 through 20 list the loads and flow weighted concentrations for the DPA, combined Mud and Salt Sloughs, and the San Joaquin River near Patterson, respectively. A detailed discussion of the methodology used to compute loads can be found in Grober *et al* (1998).

Table 17. Flow Measuring Devices in the Grassland Watershed and Lower San Joaquin River

Station	Measuring Device	Responsible Agency[1]
Charleston Drain (CH-1)	Propeller Meter	CDD
Firebaugh Main Drain (FC-5)	Stage Recorder	CCID
Pacheco Outlet (PO-1)	Weir	PWD
Panoche Drain (PE-14)	Stage Recorder	DWR
Mud Slough near Gustine	Stage Recorder	USGS
Salt Slough at Highway 165	Stage Recorder	USGS
San Joaquin River near Patterson	Stage Recorder	USGS/DWR
San Joaquin River near Vernalis	Stage Recorder	DWR
		USGS/USBR/DWR

1: Agency Codes: Charleston Drainage District (CDD), Central California Irrigation District CCID, Pacheco Water District (PWD), California Department of Water Resources (DWR), United States Geological Survey, (USGS), United States Bureau of Reclamation (USBR)

Compared with discharge, loads of TDS, boron and selenium from the DPA account for a disproportionately high percentage of total downstream loads (Table 21). Salt from the DPA accounts for an average of 51 percent of the annual load in the sloughs, 29 percent in the San Joaquin River near Patterson, and 24 percent in the San Joaquin River near Vernalis. These percentages vary somewhat from year to year but salt loads are progressively higher downstream in the watershed for all years (Figure 22). This increase occurs because although significant quantities of water may be diverted from water bodies for use as irrigation supply water, significant additional sources of salt downstream of the DPA contribute to the total load in Mud Slough, Salt Slough, and the San Joaquin River. As for discharge, annual TDS loads for the San Joaquin River sites are highest in the wet WYs, 1995 and 1986. Salt load from the DPA is highest in WY 1987, following the wet year of 1986 in the San Joaquin Valley. The next highest loads from the DPA, occurred in WYs 1995, 1988, and 1986, respectively. As for discharge, the highest TDS loads from the DPA seem to be related to antecedent hydrologic conditions in the San Joaquin River. The lowest loads in the DPA occurred in WYs 1991 and 1992, the same years with the lowest discharge from the DPA.

The pattern of boron loading is similar to TDS except a higher percentage of boron in the watershed comes from the DPA. Boron from the DPA accounts for an average of 67 percent of the load in the sloughs, 51 percent at Patterson, and 45 percent at Vernalis (Table 21). Boron loads are generally highest downstream in the watershed except in WYs 1986 and 1988 when boron loads

Table 18. Annual Load and Flow Weighted Concentration from the Drainage Problem Area for Water Years 86-95.

Water Year	Flow (acre-feet)	Flow Weighted Load Se (lbs)	Flow Weighted Load B (1000 lbs)	Flow Weighted Load TDS (tons)	Flow Weighted Concentration Se (µg/L)	Flow Weighted Concentration B(mg/L)	Flow Weighted Concentration TDS (mg/L)
1986	67,006	9,524	787	214,250	52.3	4.32	2,351
1987	74,902	10,959	889	241,526	53.8	4.37	2,371
1988	65,327	10,097	821	236,301	56.8	4.62	2,660
1989	54,186	8,718	743	202,420	59.2	5.04	2,747
1990	41,662	7,393	672	171,265	65.2	5.93	3,023
1991	29,290	5,858	544	129,899	73.5	6.83	3,261
1992	24,533	5,083	435	110,327	76.2	6.53	3,307
1993	41,197	8,856	730	183,021	79.0	6.51	3,267
1994	38,670	8,468	645	171,495	80.5	6.13	3,261
1995	57,574	11,875	868	237,530	75.8	5.55	3,034
Sum of Avgs	494,348	86,830	7,136	1,898,034	64.6	5.31	2,823

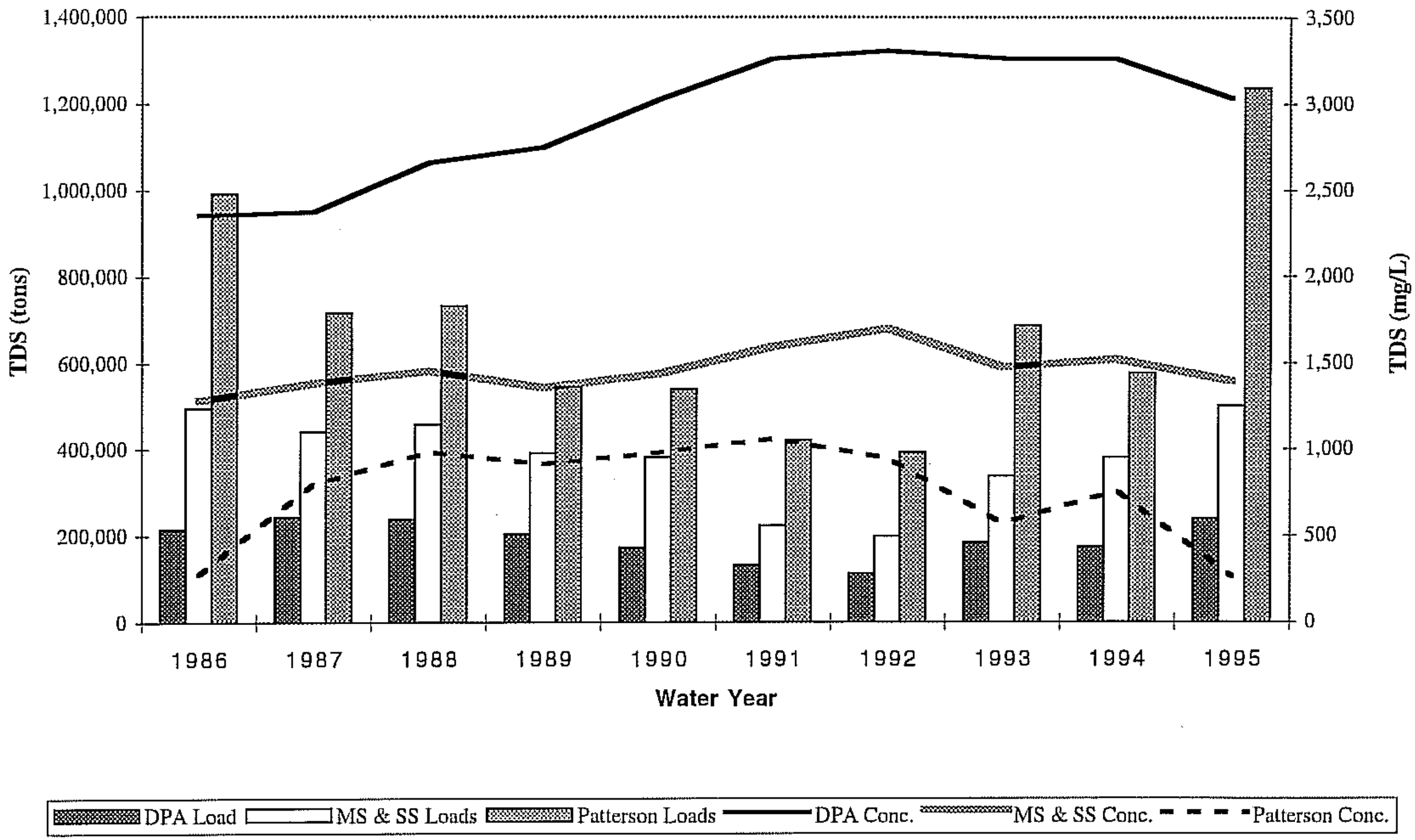
Table 19. Combined Mud Slough (north) and Salt Slough Annual Loads for Water Years 86-95.

Water Year	Flow (acre-feet)	Flow Weighted Load Se (lbs)	Flow Weighted Load B (1000 lbs)	Flow Weighted Load TDS (tons)	Flow Weighted Concentration Se (µg/L)	Flow Weighted Concentration B(mg/L)	Flow Weighted Concentration TDS (mg/L)
1986	284,316	6,643	1,368	494,544	8.6	1.77	1,279
1987	233,843	7,641	1,265	438,904	12.0	1.99	1,380
1988	230,454	8,132	1,301	455,956	13.0	2.08	1,455
1989	211,393	8,099	1,139	389,325	14.1	1.98	1,354
1990	194,656	7,719	1,121	380,564	14.6	2.12	1,438
1991	102,162	3,899	612	221,542	14.0	2.20	1,595
1992	85,428	2,919	522	197,352	12.6	2.25	1,699
1993	167,955	6,871	1,066	336,522	15.0	2.33	1,473
1994	183,546	7,980	1,116	379,408	16.0	2.24	1,520
1995	263,769	10,694	1,459	499,339	14.9	2.03	1,392
Sum of Avgs	1,957,522	70,597	10,970	3,793,457	13.3	2.06	1,425

Table 20. Annual Loads in the San Joaquin River near Patterson for Water Years 86-95.

Water Year	Flow (acre-feet)	Flow Weighted Load Se (lbs)	Flow Weighted Load B (1000 lbs)	Flow Weighted Load TDS (tons)	Flow Weighted Concentration Se (µg/L)	Flow Weighted Concentration B(mg/L)	Flow Weighted Concentration TDS (mg/L)
1986	2,676,764	11,305	2,546	991,086	1.6	0.35	272
1987	662,135	8,857	1,681	715,301	4.9	0.93	794
1988	549,412	9,330	1,854	731,877	6.2	1.24	980
1989	438,398	7,473	1,305	543,916	6.3	1.09	912
1990	404,163	6,125	1,142	537,896	5.6	1.04	979
1991	291,223	3,548	760	419,457	4.5	0.96	1,059
1992	304,151	3,064	740	391,336	3.7	0.89	946
1993	891,230	8,379	1,643	686,212	3.5	0.68	566
1994	562,301	7,270	1,260	574,735	4.8	0.82	752
1995	3,504,034	14,291	2,296	1,236,981	1.6	0.24	260
Sum of Avgs	10,283,811	79,643	15,226	6,828,798	2.8	0.54	488

Figure 22. Annual Salt Load and Concentration for the Drainage Problem Area, Sloughs, and San Joaquin River at Patterson: WYs 86-95



are slightly higher at Patterson than at Vernalis (Figure 23). The lower load at Vernalis may be attributable to inconsistencies in the data used to compute loads (Grober *et al*, 1998).

The pattern of generally increasing constituent loading further downstream in the watershed is significantly different for selenium than for TDS and boron (Figure 24). Selenium loads are higher for the DPA than for combined Mud and Salt Sloughs in all years except 1990. Loads for the DPA are also higher than loads for the San Joaquin River near Patterson except for the wet water years of 1986 and 1995. Selenium loads for the San Joaquin River near Vernalis exceed calculated loads for the DPA only in these two wet years and are approximately equal to DPA loads in WYs 1990 and 1993. Selenium loads at Vernalis exceeded the combined loads for the sloughs in all years except 1990, 1991, and 1994, although even in these years loads at Vernalis were less than eight percent lower than the sloughs. Vernalis loads exceeded Patterson loads in all years except 1987 and 1988.

The combined effects of reduced water supplies with improved on-farm irrigation practices is apparent in the large reductions in loads of all constituents that occurred from the DPA between WYs 1989 and 1992. These load reductions were credited with the less severe and less frequent exceedance of water quality objectives (Table 15) in the San Joaquin River at the Crows Landing Bridge site (Karkoski and Tucker, 1993a). Increased concentrations were likely due to the reduced availability of better quality tail water that would have reduced the concentrations in the drainage water. The reduction in tail water results from improved irrigation management and less water deliveries. The trend toward reduced loads was reversed in water year 1993. This increase was attributed to improved water supplies and the increased leaching of salts from the DPA (Chilcott *et al.*, 1995a) . Loads from the DPA increased dramatically in water year 1995; boron and selenium loads were the highest on record since monitoring began in 1985 and TDS loads were higher in only WY 1987. The leaching of accumulated salts built up in the soil profile during six years of drought may account for some of the load increases from the DPA in 1995.

Salt and boron are ubiquitous throughout the Grassland Watershed and the western portion of the San Joaquin River Basin, but selenium is primarily found in subsurface drainage from the DPA. One would expect selenium loads to be roughly equal in the DPA, combined sloughs and SJR sites, but this is not the case. Small differences in loads between sites can be attributed to random errors associated with data collection and measurement, or introduced through the methodology used to compute loads. But the consistently higher loads calculated for the DPA relative to downstream sites and the significantly higher loads for downstream SJR sites in wet water years both merit further discussion.

Since all agricultural drainage from the DPA drains to the sloughs, the difference in loads between the DPA and the combined sloughs must be accounted for by data error, actual losses, or a combination of the two. Calculated loads for the combined sloughs and the SJR sites are based on daily USGS flow data for well defined sites at which water quality samples were collected at various intervals. Loads for the DPA are based on discharge data collected at four individual sites that must then be adjusted to account for losses due to recirculation. The discharge data for the four individual sites is of poorer quality than the USGS river sites and the adjustments made for losses from these four sites may be poorly defined. This may account, in part, for the observed loss of selenium between the DPA and the combined slough sites. Investigation into the mechanism of actual losses from the system have been inconclusive (USBR, 1995). Some possible explanations for the losses include seepage losses from canals, diversions into wetlands due to incomplete flushing from water supply channels, and losses to sediments in channels. The impact of either an actual loss or an artificial loss caused by data error would also affect loads of salt and boron but this loss would not be readily apparent because of the significant loading of these constituents from sources outside of the DPA.

Figure 23. Annual Boron Load and Concentration for the Drainage Problem Area, Sloughs, and San Joaquin River at Patterson: WYs 86-95

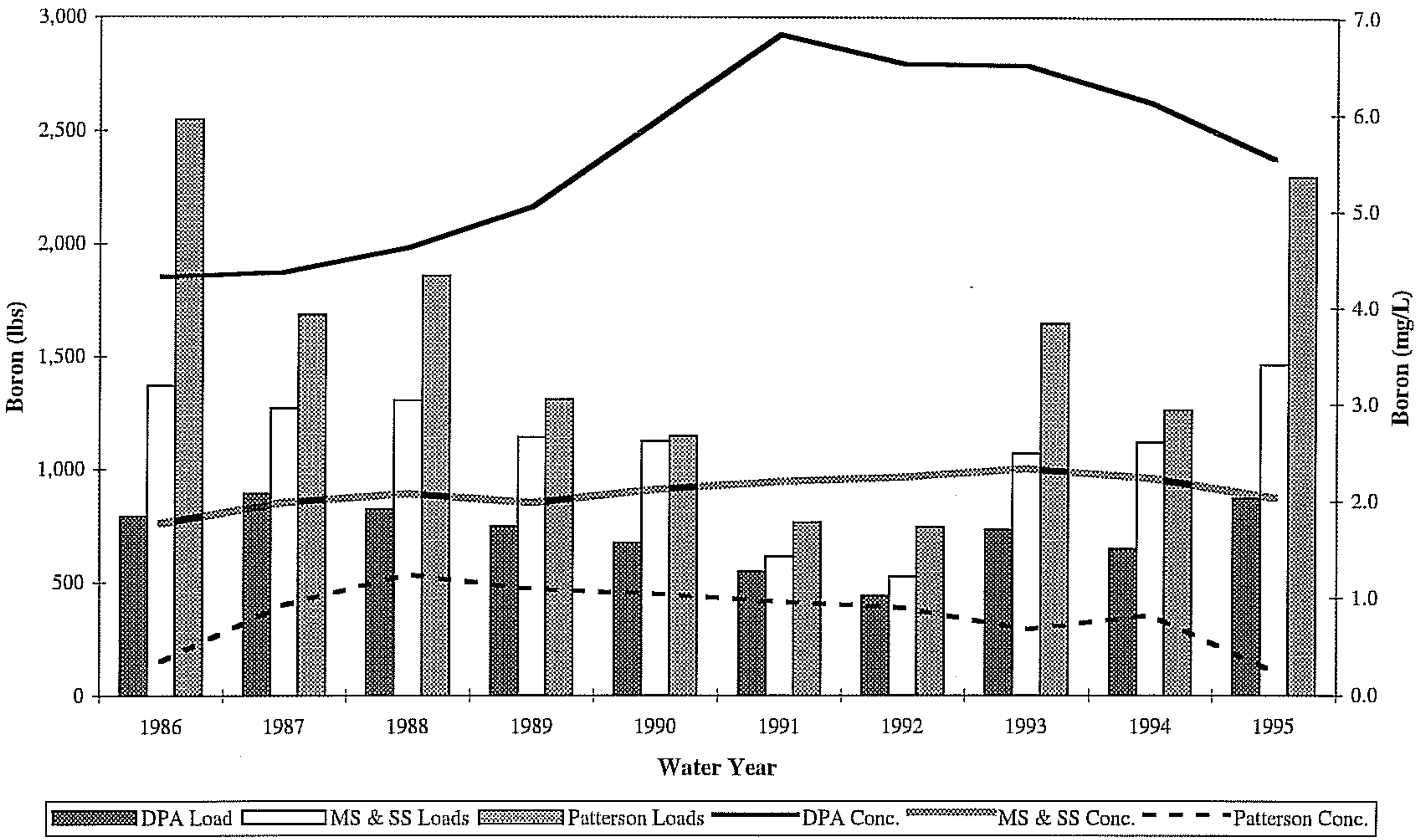
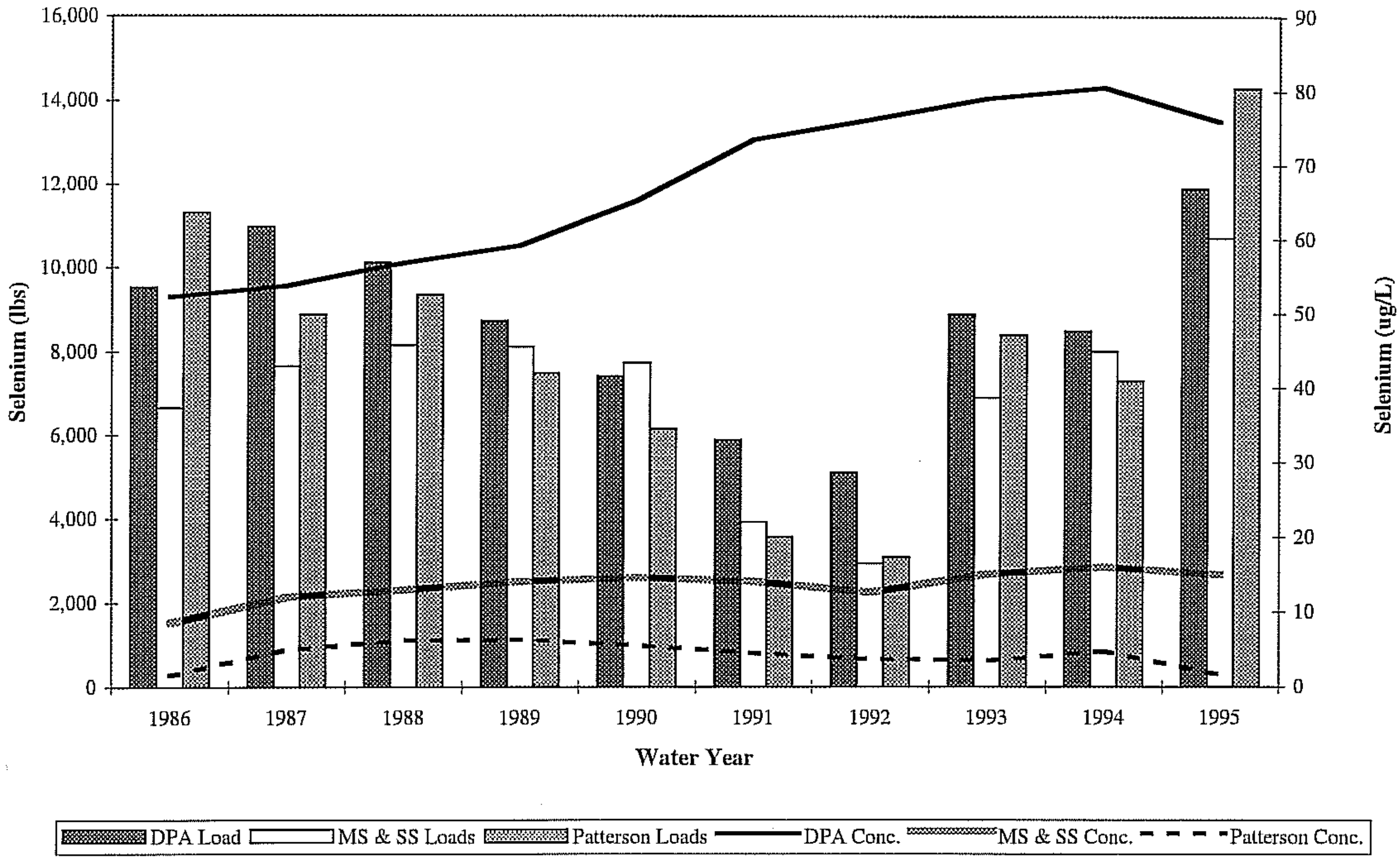


Figure 24. Annual Selenium Load and Concentration for the Drainage Problem Area, Sloughs, and San Joaquin River at Patterson: WYs 86-95



Occurrence of significantly higher selenium loads for the Vernalis site than the Patterson and the combined sloughs sites in wet years appears to be inconsistent with the presumption that most selenium is associated with subsurface agricultural drainage from the DPA. This presumption may either be incorrect (at least in wet years) or the difference in loads may be attributable to data error, or a combination of the two.

Although the DPA does indeed contribute most of the selenium to the San Joaquin River, it is not the only source. Selenium in low concentrations (less than $1\mu g/L$) may be added to the lower San Joaquin River from a wide range of sources including main stem San Joaquin River subsurface agricultural return flows, surface return flows, groundwater accretions, and tributary inflows. Another possible source of selenium in the main stem of the San Joaquin River is remobilization of selenium from sediment in the river itself. Finally, loads may at times be overestimated because of the methodology used to calculate loads but the consistently higher loads at downstream sites suggests that differences cannot be entirely attributed to data error or calculation error. The consistently higher loads that are observed would suggest that there is some consistent error in the measurement of selenium concentration, discharge measurement, or load calculation. No such consistent errors have been identified except those associated with periods of rapidly changing discharge and concentration in conjunction with sparse sampling. An expanded discussion of salt, boron, and selenium loads, calculated for the DPA, Mud Slough (north), Salt Slough, and the San Joaquin River for WYs 1986 through 1995 is presented in Grober *et al.*,(1998).

REFERENCES

Chilcott, J.E., Westcot, D.W., Werner, K.M., and Belden, K.K., 1988. *Water Quality Survey of Tile Drainage Discharges in the San Joaquin River Basin.* Regional Water Quality Control Board, Central Valley Region Report.

Chilcott, J.E., Westcot, D.W., Belden, K.K., and O'Connor, K. A., 1989. *Agricultural Drainage Contribution to Water Quality in the Grassland Area of Western Merced County, California. October 1987 through September 1988.* Regional Water Quality Control Board, Central Valley Region Report.

Chilcott, J.E., Karkoski, J., Ryan, M.M., and Laguna, C. 1995a. *Water Quality of the Lower San Joaquin River: Lander Avenue to Vernalis, October 1992 through September 1994, (Water Years 1993 and 1994).* Regional Water Quality Control Board, Central Valley Region Report.

Chilcott, J.E., Karkoski, J., and Ryan, M.M., 1995b. *Agricultural Drainage Contribution to Water Quality in the Grassland Area of Western Merced County, California. October 1992 through September 1993.* Regional Water Quality Control Board, Central Valley Region Report.

CVRWQCB (Central Valley Regional Water Quality Control Board). 1996 Draft. *Beneficial Use Assessment of Grassland Area Water Bodies.* Regional Water Quality Control Board, Central Valley Region Report.

DWR (California Department of Water Resources 1995). *California Water Supply Outlook,* October 1994 through September 1995. Division of Flood Management.

Grober, L., Karkoski, J. And Dinkler, L. 1998. *A Total Maximum Monthly Load Model for the San Joaquin River.* Regional Water Quality Control Board, Central Valley Region Report.

James, E.W., Grewell, B.J., Westcot, D.W., Beldon, K.K., and Boyd, T.F. 1988a. *Water Quality of the Lower San Joaquin River: Lander Avenue to Vernalis, May 1985 through March 1988.* Regional Water Quality Control Board, Central Valley Region Report.

James, E.W., Westcot, D.W., Grewell, B.J., Belden, K.K., Boyd, T.F., Waters, R.I, and Thomasson, R.R. 1988b. *Agricultural Drainage Contributions to Water Quality In the Grassland Area of Western Merced County, California.* Regional Water Quality Control Board, Central Valley Region Report.

Karkoski, J. 1994. *A Total Maximum Monthly Load Model for the San Joaquin River.* Regional Water Quality Control Board, Central Valley Region Report.

Karkoski, J. and Tucker, R.T., 1993a. *Water Quality of the Lower San Joaquin River: Lander Avenue to Vernalis, October 1991 through September 1992, (Water Year 1992).* Regional Water Quality Control Board, Central Valley Region Report.

Karkoski, J. and Tucker, R.T, 1993b. *Agricultural Drainage Contribution to Water Quality in the Grassland Area of Western Merced County, California. October 1991 through September 1992, (Water Year 1992).* Regional Water Quality Control Board, Central Valley Region Report.

Marshack, J.B., 1993. *A Compilation of Water Quality Goals.* Regional Water Quality Control Board, Central Valley Region Report.

Pierson, F.W., James, E.W. and Thomasson, R.R., 1989a. *Hydrology Study of Mud Slough (North), Merced County.* Regional Water Quality Control Board, Central Valley Region Report.

Pierson, F.W., James, E.W. and Thomasson, R.R., 1989b. Hydrology Study of Salt Slough, Merced County. Regional Water Quality Control Board, Central Valley Region Report.

Shelton, L.R. and Miller, L.K., 1988. *Water Quality Data, San Joaquin Valley, California, March 1985 through March 1987.* U.S. Geological Survey, Open-File Report 88-479.

Shelton, L.R. and Miller, L.K., 1991. *Water Quality Data, San Joaquin Valley, California, April 1987 through September 1988.* U.S. Geological Survey, Open-File Report 91-74.

SWRCB (State Water Resources Control Board, Cal EPA). 1995. *Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary.*

Steensen, R.A., Chilcott, J.E., and Burns, T. 1996a. *Water Quality of the Lower San Joaquin River: Lander Avenue to Vernalis, October 1994 through September 1995, (Water Year 1995).* Regional Water Quality Control Board, Central Valley Region Report

Steensen, R.A., Chilcott, J.E., and Burns, T. 1996b. *Agricultural Drainage Contributions to Water Quality in the Grassland Area of Western Merced County, California, October 1994 through September 1995, (Water Year 1995).* Regional Water Quality Control Board, Central Valley Region Report.

USBR (United States Bureau of Reclamation). 1994. *Draft Water Quality data available for the Mendota Pool and the Delta Mendota Canal at Mile Post 116.48.* Environmental Monitoring Branch, Mid Pacific Region.

USBR (U.S. Bureau of Reclamation). 1995. *Finding of No Significant Impact and Supplemental Environmental Assessment, Grassland Bypass Project, Interim Use of a Portion of the San Luis Drain for Conveyance of Drainage Water Through the Grassland Water District and Adjacent Grassland Areas.* Mid Pacific Region, Sacramento, California, November, 1995.

Vargas, A., Karkoski, J., and Ryan, M.M., 1995. *Agricultural Drainage Contribution to Water Quality in the Grassland Area of Western Merced County, California. October 199 through September 1994.* Regional Water Quality Control Board, Central Valley Region Report.

Westcot, D.W., Grewell, B.J., and Belden, K.K. 1989. *Water Quality of the Lower San Joaquin River: Lander Avenue to Mossdale Bridge, October 1987 through September 1988.* Regional Water Quality Control Board, Central Valley Region Report.

Westcot, D.W., Enos, C.A., and Fastenau. 1990a. *Water Quality of the Lower San Joaquin River: Lander Avenue to Vernalis, October 1988 through September 1989 (Water Year 1989).*

Westcot, D.W., Chilcott, J.E., Enos, C.A., and Rashmawi, E A., 1990b. *Agricultural Drainage Contribution to Water Quality in the Grassland Area of Western Merced County, California. October 1988 through September 1989 (Water Year 1989).* Regional Water Quality Control Board, Central Valley Region Report.

Westcot, D.W., Fastenau, and Enos, CA., 1991a. *Water Quality of the Lower San Joaquin River: Lander Avenue to Vernalis, October 1989 through September 1990 (Water Year 1990).* Regional Water Quality Control Board, Central Valley Region Report.

Westcot, D.W., Chilcott, J.E., and Enos, C A., 1991b. *Agricultural Drainage Contribution to Water Quality in the Grassland Area of Western Merced County, California. October 1989 through September 1990 (Water Year 1990).* Regional Water Quality Control Board, Central Valley Region Report.

Westcot, D.W., Chilcott, J.E., and Wright. T. S. 1992a. *Water Quality of the Lower San Joaquin River: Lander Avenue to Vernalis, October 1990 through September 1991 (Water Year 1991).* Regional Water Quality Control Board, Central Valley Region Report.

Westcot, D.W., Chilcott, J.E., and Wright, T.S., 1992b. *Agricultural Drainage Contribution to Water Quality in theGrassland Area of Western Merced County, California. October 1990 through September 1991 (Water Year 1991).* Regional Water Quality Control Board, Central Valley Region Report.